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La sténose spinale lombaire : identification des déterminants physiques et psychologiques responsables du déclin des capacités fonctionnelles

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Cette thèse intitulée

La sténose spinale lombaire : identification des déterminants physiques et psychologiques responsables du déclin des capacités fonctionnelles

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Résumé

La sténose spinale lombaire (SSL) est une condition neuromusculosquelettique découlant du processus dégénératif du rachis lombaire. La principale manifestation clinique de la SSL est la claudication neurogène (CN). Celle-ci engendre de nombreuses limitations fonctionnelles et plus particulièrement une diminution de la capacité de marche. À ce jour, les interventions thérapeutiques visant à améliorer la capacité de marche des patients ayant un diagnostic de SSL comprennent un éventail d'options allant des interventions conservatrices comme les exercices et l'éducation aux interventions plus invasives comme la chirurgie. Bien que les récents guides de bonnes pratiques suggèrent que les interventions conservatrices devraient être pleinement exploitées avant d'avoir recours à la chirurgie, il n'existe aucune option thérapeutique conservatrice active spécifiquement dédiée à l'amélioration de la capacité de marche des patients ayant un diagnostic de SSL avec CN. Ainsi, cette thèse doctorale visait à identifier les facteurs physiques et psychologiques associés au déclin des capacités fonctionnelles des patients ayant un diagnostic de SSL, en s'intéressant plus particulièrement à la marche, pour ensuite caractériser les paramètres de la marche chez ces patients et finalement, déterminer l'efficacité d'un programme de réadaptation combinant des exercices et de l'éducation pour améliorer leur capacité de marche. La première étude de cette thèse a permis de mettre en lumière les associations majoritairement contradictoires entre, d'une part, les différents facteurs physiques ou psychologiques présents chez les patients et, d'autre part, la capacité de marche. En outre, les observations réalisées quant aux associations ont également permis de souligner le besoin de standardiser les outils de mesure et d'identifier les mesures de résultats cliniques pertinentes pour la SSL avec CN. Cette standardisation permettrait d'améliorer la comparaison des essais cliniques et donc de mieux cibler les options thérapeutiques efficaces pour cette population. La deuxième étude de cette thèse a permis de décrire et de comparer les paramètres de la marche chez des personnes âgées sans douleur en fonction de l'âge et du sexe. Les résultats obtenus montrent des différences quant aux paramètres du patron de marche, d'une part, entre les personnes âgées de 50 à 69 ans et les personnes âgées de 70 ans et plus et, d'autre part, entre les hommes et les femmes. La troisième étude de cette thèse a permis de caractériser l'ensemble des paramètres du patron de marche chez les patients ayant un diagnostic de SSL. L'ensemble des paramètres du patron de marche à l'exception des paramètres de dégagement du pied sont significativement différents entre les patients ayant un diagnostic de SSL avec CN et les personnes âgées sans douleur. Les résultats des études 1,2 et 3 ont informés les choix méthodologiques pour le développement d'un protocole de réadaptation (étude 4) combinant des exercices et de l'éducation, dédié aux patients ayant un diagnostic de SSL avec CN, qui vise l'amélioration de la capacité de marche (temps et distance de marche). Finalement, les données préliminaires de la cinquième étude quant à l'efficacité de ce programme de réadaptation montrent que celui-ci a un effet supérieur à l'éducation seule pour l'amélioration de la capacité de marche. Des améliorations significatives ont été observées chez les patients ayant reçu le programme de réadaptation de six semaines combinant des exercices et de l'éducation et ces améliorations ont persisté au-delà de la durée du programme. Outre les améliorations de la capacité de marche, le programme de réadaptation a permis de réduire l'incapacité et l'anxiété en plus de contribuer à l'augmentation du sentiment d'auto-efficacité des patients. Le programme de réadaptation semble donc prometteur pour la prise en charge conservatrice des patients ayant un diagnostic de SSL avec CN. Cette thèse contribue de manière significative à l'avancement des connaissances et des pratiques cliniques pour la prise en charge des patients atteints de SSL avec CN.

Mots-clés : *Sténose spinale lombaire, Claudication neurogène, Capacité de marche, Facteurs psychologiques, Facteurs physiques, Capteur inertiel, Paramètres biomécaniques de la marche, Programme de réadaptation, Exercices, Éducation*

Abstract

Lumbar spinal stenosis (LSS) is a neuromusculoskeletal condition resulting from degenerative changes in the lumbar spine. The main clinical symptom of LSS is neurogenic claudication (NC), which results in various functional limitations, most notably a reduced walking capacity. To date, therapeutic interventions that aim at improving patients' walking capacity encompass a range of options, from conservative approaches such as exercise and education to more invasive procedures like surgery. While recent clinical guidelines suggest that conservative interventions should be fully explored before opting for surgery, no active conservative therapeutic option is specifically dedicated at improving walking capacity in patients diagnosed with LSS with NC. Thus, this doctoral thesis aimed to identify the physical and psychological factors associated with the decline in functional capacities in patients diagnosed with LSS, focusing particularly on walking, then to characterize gait parameters in these patients, and finally, to determine the effectiveness of a rehabilitation program combining exercise and education to improve their walking capacity. The first study of this thesis highlighted contradictory associations between the various physical and psychological factors present in patients and their walking capacity. Furthermore, the observations regarding the associations have also highlighted the need to standardize measurement tools and identify relevant clinical outcome measures for LSS with NC. This standardization would improve the comparison of clinical trials and thus better target effective therapeutic options for the population. The second study of this thesis aimed to describe and compare walking parameters in older adults without pain, according to age and sex. Results showed differences between individuals aged 50 to 60 and those aged 70 and older. Furthermore, it identified variations in walking parameters between men and women. The third study of this thesis allowed the characterization of gait parameters in patients with a diagnosis of LSS causing NC. Results showed that all gait parameters, except for foot clearance parameters, are significantly different between patients with LSS causing NC and pain-free older adults. The results of the first three studies have informed the methodological choices for the implementation of a rehabilitation protocol (Study 4) that combines exercise and education aimed at improving the walking capacity of patients with LSS causing NC. Finally, preliminary results from the fifth study on the effectiveness of this rehabilitation program showed that the combination of exercise and education has a superior effect on walking capacity compared to education alone. Significant improvements were observed in patients who received the six-week rehabilitation program combining exercise and education, and these improvements persisted beyond the program’s duration. In addition to improved walking capacity, the rehabilitation program reduced disability and anxiety and contributed to an increased self-efficacy in patients. The rehabilitation program thus appears promising for the conservative management of patients diagnosed with LSS with NC. This thesis contributes significantly to advancing knowledge and clinical practice for affected patients.

Keywords: *Lumbar spinal stenosis, Neurogenic claudication, Walking capacity, Psychological factors, Physical factors, Inertial sensor, Biomechanical gait parameters, Rehabilitation program, Exercises, Education*

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Liste des sigles et abréviations

AAPI : *Aachen Activity and Participation Index*

AINS : Anti-inflammatoire non-stéroïdien

ANOVA : *Analysis of variance*

ANCOVA : *Analysis of covariance*

AXIS : *Appraisal tool for Cross-Sectional Studies*

BMI *: Body Mass Index*

CES-D : *Center of Epidemiological Studies Depression Scale*

CINAHL : *Cumulative Index to Nursing and Allied Health Literature*

CIUSSS MCQ : Centre Intégré Universitaire de Santé et de Services Sociaux de la Mauricie et du Centre-du-Québec

CN : Claudication neurogène

CONSORT: *CONsolidated Standards Of Reporting Trials*

DASH : *Disability of the Arm, Shoulder and Hand questionnaire*

DESC : *Rasch-based Depression Screener*

EQ-5D: *EuroQoL-5D*

FC-CPSES : *French-Canadian Chronic Pain Self-Efficacy Scale*

FC-HADS : *French-Canadian Hospital Anxiety and Depression Scale*

FC-SSSQ : *French-Canadian Swiss Spinal Stenosis Questionnaire*

GDI : *Gait Disability Index*

HADS : *Hospital Anxiety and Depression Scale*

HUI : *Health Utilities Index Mark 3*

IMUs : *Inertial Measurement Units*

IPAQ : *International Physical Activity Questionnaire*

IRM : Imagerie par résonance magnétique

ITB : Indice Tibio-Brachial

JOABPEQ : *Japanese Orthopedic Association Back Pain Evaluation Questionnaire*

LSS : *Lumbar Spinal Stenosis*

MAP : Maladie Artérielle Périphérique

MCID : *Minimal Clinically Important Difference*

MaxHC : *Maximum Heel Clearance*

MinTC : *Minimal Toe Clearance*

MRI : *Magnetic Resonance Imaging*

NC : *Neurogenic Claudication*

NRS *: Numerical Rating Scale*

ODI : *Oswestry Disability Index*

PASS-20 : *Pain Anxiety Symptoms Scale*

PCS : *Pain Catastrophizing Scale*

PF : Physical Functioning

PGIC : *Patient's global impression of change*

PROMs : *Patient-reported outcome measures*

QAPPA : Questionnaire d'activité physique pour les personnes âgées

QBPDS : *Quebec Back Pain Disability Scale*

QoL : *Quality of Life*

RCT : *Randomized Controlled Trial*

RMDQ : *Roland-Morris Disability Questionnaire*

ROM : *Range of Motion*

SF-12 : *12-Item Short Form Survey*

SF 36 : *36-Item Short Form Survey*

SPPB : *Short Physical Performance Battery*

SPWT : *Self-Paced Walking Test*

SSL : Sténose spinale lombaire

SSSQ : *Swiss Spinal Stenosis Questionnaire*

TSK : *Tampa Scale of Kinesiophobia*

UQTR : Université du Québec à Trois-Rivières

VAS : Visual Analog Scale

ZCQ : *Zurich Claudication Questionnaire*

The journey of a thousand miles must begin with a single step.

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Introduction – Mise en contexte

Selon l'Organisation mondiale de la santé (OMS), la proportion de personnes âgées à travers le monde connaît, depuis quelques années, une forte croissance. En effet, on estime qu'entre 2015 et 2050, la proportion de personnes âgées de 60 ans et plus à travers le monde augmentera de 12 à 22%. Déjà en 2020, la proportion de personnes âgées surpassait le nombre d'enfants âgés de moins de cinq ans (Organisation Mondiale de la Santé, 2022). Plus près de nous, le Canada et le Québec n'échappent pas à cette transformation démographique importante puisque près d'une personne sur cinq est actuellement âgée de 65 ans ou plus (Institut de la statistique du Québec, 2022; Statistique Canada, 2022). En 2023, et pour la première fois dans l'histoire du pays, le nombre de personnes âgées de plus de 65 ans surpassait le nombre de personnes âgées de 18 ans et moins (Statistique Canada, 2024). Ce vieillissement important de la population s'explique notamment par l'avancée en âge des personnes appartenant au groupe des baby-boomers (1946-1964), la baisse du taux de mortalité, la hausse de l'espérance de vie et la diminution du seuil de fécondité (Agence de la santé publique du Canada, 2020; Statistique Canada, 2022).

Ces changements démographiques soulèvent plusieurs inquiétudes, notamment en raison de la forte prévalence de maladies et d'affections chroniques présentes chez les personnes âgées. En effet, plus de 73% de la population canadienne âgée de 65 ans ou plus présente au moins une des 10 maladies ou conditions chroniques les plus courantes. Parmi ces affections, l'arthrose diagnostiquée représente la condition musculosquelettique la plus prévalente chez les aînés avec une prévalence annuelle d'environ 38% (Agence de la santé publique du Canada, 2020).

L'arthrose, qui se caractérise par l'échec du processus de réparation du cartilage articulaire endommagé en raison de nombreux changements biomécaniques et biologiques dans l'articulation (Bijlsma et al., 2011; Wenham & Conaghan, 2010), est la forme d'arthrite la plus courante (Agence de la santé publique du Canada, 2020; Goode et al., 2013). Le vieillissement est d'ailleurs le plus important facteur de risque prédisposant une personne à l'arthrose. D'autres facteurs de risque non modifiables comme le fait d'être une femme, la génétique, l'ethnie ainsi que des facteurs modifiables associés aux habitudes de vie (p. ex., obésité, mauvaise alimentation, niveau d'activité physique plutôt faible) peuvent également contribuer au développement de l'arthrose (Johnson & Hunter, 2014). Même si l'arthrose fait partie intégrante du processus normal de vieillissement, les manifestations qui en découlent et leurs conséquences affectent chaque personne de manière variable. Bien qu'il n'existe aucune intervention permettant de guérir cette condition dégénérative, plusieurs interventions, dont la modification de certaines habitudes de vie telle que la pratique de l'activité physique, peuvent contribuer au ralentissement de sa progression en plus de permettre de réduire les douleurs associées à l'arthrose et d'améliorer la fonction (Agence de la santé publique du Canada, 2020; Bijlsma et al., 2011; Nelson et al., 2014).

Au niveau du rachis lombaire, les processus dégénératifs associés à l'arthrose comme la formation d'ostéophytes peuvent provoquer un rétrécissement du canal central vertébral. Ce rétrécissement, résultant de la dégénérescence des vertèbres lombaires, est appelé sténose spinale lombaire (SSL)(Laplante & DePalma, 2012). La SSL est d'ailleurs l'une des plus fréquentes conditions dégénératives chez les personnes de plus de 50 ans (K. Otani et al., 2013; Porter, 1996) en plus d'être une cause commune de douleur et d'incapacité chez la personne âgée, et ce, à l'échelle mondiale (Deyo et al., 2010; Ishimoto et al., 2013; Kalichman et al., 2009; Katz et al., 2022). Elle représente également la cause la plus commune de chirurgie de la colonne vertébrale chez les individus de 65 ans et plus (Ciol et al., 1996; Deyo et al., 2010; Szpalski & Gunzburg, 1998). La principale manifestation clinique de la SSL, la claudication neurogène (CN), est directement responsable de la diminution de la participation des personnes atteintes aux activités de la vie quotidienne (p. ex., marche) en plus de contribuer à l'augmentation de leur isolement social. En effet, les symptômes associés à la CN (p. ex., engourdissements, faiblesses et fatigue dans le dos et/ou les jambes) se manifestent lors de la station debout prolongée et la marche et sont soulagés par l'adoption de la position assise ou penchée vers l'avant (Comer et al., 2009; Katz & Harris, 2008). On estime que près de 75% des patients ayant un diagnostic de SSL avec CN sont dans l'impossibilité de compléter plus de 10 minutes consécutives d'activité physique (Norden et al., 2017). L'incapacité et la douleur associées à la SSL avec CN sont des éléments déterminants dans le diagnostic et dans la prise en charge des patients (Carlo Ammendolia et al., 2017; Cook et al., 2020; Genevay et al., 2018) en plus d'être des sources de préoccupations importantes pour ceux-ci (Carlo Ammendolia et al., 2017; Allyn M Bove et al., 2018).

Au regard des recommandations issues des guides de bonnes pratiques cliniques, les interventions thérapeutiques conservatrices comme l'éducation et les exercices doivent être pleinement exploitées avant d'envisager des interventions plus invasives comme la chirurgie (Bussières et al., 2021). Il n'existe cependant pas de ressources spécifiques dédiées aux patients ayant un diagnostic de SSL avec CN, et ce, peu importe le stade de la condition. Pourtant, la progression généralement lente de la SSL offre la possibilité d'utiliser les interventions conservatrices, dont les exercices, de manière sécuritaire (Marchand et al., 2021). Le développement de soins conservateurs adaptés est donc essentiel afin d'améliorer la prise en charge des patients ayant un diagnostic de SSL avec CN en plus de les impliquer activement dans leur réadaptation et contribuer à l'amélioration de leur qualité de vie. Ainsi, les travaux de cette thèse s'inscrivent dans une perspective plus générale visant, dans un premier temps, à identifier les facteurs physiques et psychologiques associés au déclin des capacités fonctionnelles des patients ayant un diagnostic de SSL, en s'intéressant plus particulièrement à la marche pour, dans un deuxième temps, caractériser les paramètres de la marche chez ces patients et finalement, déterminer l'efficacité d'un programme de réadaptation combinant exercices et éducation pour améliorer leur capacité de marche. Nous croyons que l'identification des facteurs physiques et psychologiques associés au déclin de la capacité de marche des patients permettra de mieux comprendre les besoins des patients en matière d'éducation et de réadaptation. Nous croyons également que les participants prenant part à un programme de réadaptation spécifique combinant de l'éducation et des exercices bénéficieront d'une plus grande amélioration de leur capacité de marche que les participants ayant accès à de l'éducation uniquement.

Tous les travaux présentés dans cette thèse ont été réalisés dans le cadre du programme de Doctorat en sciences biomédicales de l'Université de Montréal offert en extension à l'Université du Québec à Trois-Rivières. Cette thèse est présentée sous forme de thèse par articles et est composée de six chapitres.

Le premier chapitre définit et met en contexte la sténose spinale lombaire, la claudication neurogène, la capacité de marche, les principaux outils cliniques (tests et questionnaires) pouvant être utilisés dans l'évaluation, les facteurs physiques et psychologiques impliqués le déclin de la capacité de marche ainsi que les lignes directrices en matière de prise en charge des patients ayant un diagnostic de SSL.

Le deuxième chapitre de cette thèse présente le premier article, publié dans la revue *Frontiers in Neurology* en septembre 2021. Cet article fait état des connaissances actuelles concernant les facteurs physiques et psychologiques associés à la capacité de marche des patients ayant un diagnostic de SSL avec CN. Ce bilan des connaissances a permis d'identifier les facteurs physiques et psychologiques ayant le potentiel d'influencer la capacité de marche chez les patients ayant un diagnostic de SSL avec CN. Ces facteurs ont par la suite été pris en considération dans l'élaboration des différents projets de recherche réalisés dans le cadre de cette thèse.

Le troisième chapitre présente le deuxième article de la thèse, soumis dans la revue *Journal of Aging and Physical Activity* en octobre 2024. Cet article décrit les différences observées au niveau des caractéristiques du patron de marche chez des personnes âgées de 50 ans et plus en fonction du groupe d'âge (50-59 ans, 60-69 ans et 70 et + ans) et du sexe. Il met en lumière les changements liés au vieillissement et identifie les différences quant aux caractéristiques du patron de marche entre les hommes et les femmes de 50 ans et plus. Cet article a permis d'obtenir des valeurs de références, mesurées à l'aide de capteurs inertiels, pour l'ensemble des caractéristiques du patron de marche des personnes âgées de 50 ans et plus.

Le quatrième chapitre aborde les caractéristiques du patron de marche des patients ayant un diagnostic de SSL avec CN en comparaison à des personnes âgées sans douleur. Sachant que le vieillissement même peut engendrer des modifications au patron de marche, l'identification des changements aux caractéristiques du patron de marche des patients ayant un diagnostic de SSL avec CN a permis de mieux cibler les besoins en matière de réadaptation et de mieux comprendre les limitations à la marche. Cet article a été soumis dans *BMC Geriatrics* en 2024.

Le cinquième chapitre décrit, par l'entremise du troisième article publié dans *Trials* en décembre 2022, le protocole de recherche de notre étude randomisée et contrôlée visant à déterminer l'effet d'un programme de réadaptation de 6 semaines incluant des exercices et de l'éducation sur la capacité de marche des patients ayant un diagnostic de SSL avec CN. Le protocole a été enregistré le 22 août 2022 auprès de la U.S. National Library of Medicine via ClinicalTrials.gov (NCT05 513326).

Le sixième chapitre de cette thèse présente les données préliminaires issues de l'étude contrôlée randomisée visant à déterminer l'effet d'un programme de réadaptation de 6 semaines incluant des exercices et de l'éducation sur la capacité de marche des patients ayant un diagnostic de SSL avec CN. Les principaux résultats préliminaires de cet article indiquent qu'un programme de réadaptation de 6 semaines combinant des exercices et de l'éducation a un effet supérieur à l'éducation seule sur l'amélioration du temps de marche avant les premiers symptômes, le temps de marche total ainsi que la distance de marche avant les premiers symptômes. De plus, les résultats préliminaires indiquent que le programme de réadaptation a un effet supérieur sur la réduction de l'incapacité liée à la SSL et de l'anxiété ainsi que sur l'augmentation du sentiment d'auto-efficacité en comparaison à l'éducation seule. Cette étude est, à notre connaissance, la première à détailler le contenu et les modalités d'intervention à la fois pour les exercices proposés et les séances d'éducation.

Finalement, le dernier et septième chapitre permet de faire les liens entre les résultats obtenus au cours des différentes études présentées dans cette thèse et l'état des connaissances actuelles sur la prise en charge des patients atteints de SSL. Ce chapitre propose donc une discussion générale, une discussion sur les forces et limites de la thèse en plus de présenter les perspectives de recherche découlant de la thèse.

Chapitre 1 – Pas à pas vers la réadaptation de la sténose spinale lombaire

1. La sténose spinale lombaire (SSL)

1.1 Anatomie générale de la colonne lombaire

La colonne vertébrale, aussi connue sous le nom du rachis, joue plusieurs rôles importants chez l'humain. Elle permet d'abord de protéger la moelle épinière en plus d'assurer la mobilité du tronc, de la tête et du bassin et d'assurer un soutien structurel (Oxland, 2016). La colonne vertébrale est composée de vertèbres et de disques intervertébraux. Elle se divise en 5 grandes régions, soit la colonne cervicale, la colonne thoracique, la colonne lombaire, le sacrum et le coccyx. Comme les travaux de cette thèse s'intéressent principalement à la SSL, seules les structures anatomiques se trouvant dans la région lombaire (voir figure 1.1) seront sommairement décrites dans cette thèse.

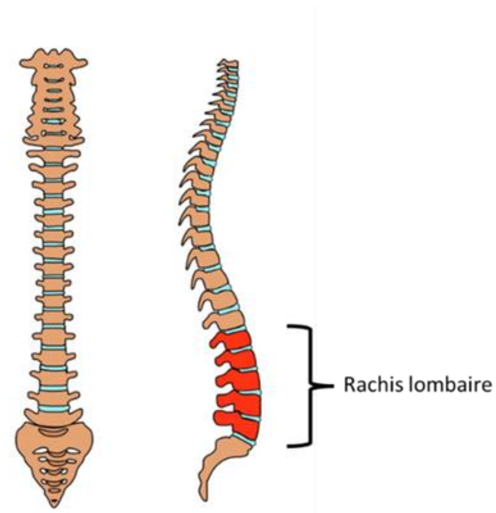

Figure 1.1 - Vues frontale et sagittale de la colonne vertébrale

Image tirée et adaptée de https://chirurgie-dos.com/le-spondylolisthesis/anatomie-de-la-colonne-vertebrale-le-spondylolisthesis/

La colonne vertébrale lombaire est composée de cinq vertèbres qui sont articulées les unes avec les autres. Une vertèbre lombaire typique est constituée d'un corps vertébral dans sa partie antérieure et d'un arc vertébral qui forme les parties latérales et postérieures du foramen vertébral. Les corps vertébraux des vertèbres lombaires sont de plus grande taille que ceux des autres régions de la colonne vertébrale. Chaque corps vertébral est relié aux vertèbres adjacentes par l'entremise de disques intervertébraux et de ligaments. Postérieurement, l'arc vertébral de chaque vertèbre est formé de deux pédicules ainsi que de deux lames. La superposition des foramens vertébraux des cinq vertèbres lombaires forme, en partie, le canal vertébral aussi appelé canal rachidien qui abrite et protège la moelle épinière. La portion antérieure de ce canal est délimitée par la surface postérieure des vertèbres lombaires, des disques ainsi que par le ligament longitudinal postérieur tandis que la portion postérieure est délimitée par les lames des vertèbres et le ligament jaune. Le ligament jaune est une structure ligamentaire courte et épaisse qui permet de relier les lames de deux vertèbres consécutives et recouvre symétriquement les côtés gauche et droit de la face postérieure du canal vertébral (Bogduk, 2022; Sassack & Carrier, 2023).

La vertèbre typique lombaire possède également quatre processus articulaires (2 supérieures et 2 inférieures) sur lesquels se trouvent des facettes articulaires qui s'assemblent avec les facettes des processus articulaires des vertèbres adjacentes. Les foramens intervertébraux sont, pour leur part, délimités par les incisures supérieures et inférieures des pédicules de chacune des vertèbres, le disque, les corps vertébraux ainsi que la portion latérale du ligament jaune. Ces foramens permettent le passage des vaisseaux sanguins et des nerfs provenant du canal vertébral (Bogduk, 2022; Drake et al., 2020; Mahadevan, 2018; Waxenbaum et al., 2017).

Outre le canal vertébral et les foramens intervertébraux, le récessus latéral du canal lombaire est une autre structure anatomique pouvant être impliquée dans la SSL. Comme son nom l'indique, ce récessus est en réalité une expansion latérale du canal vertébral qui est délimité par le corps vertébral antérieurement et par la lame ainsi que le bord antéromédial du processus articulaire supérieur postérieurement (Bogduk, 2022).

La forme du canal vertébral varie au niveau lombaire passant d'une forme ovale dans les niveaux supérieurs et devenant plus triangulaire et parfois en forme de trèfle dans les niveaux inférieurs. La cinquième vertèbre lombaire possède, quant à elle, quelques caractéristiques qui la distingue des autres vertèbres lombaires. En effet, cette vertèbre possède un corps vertébral et des processus transverses plus grands et la face antérieure de son corps vertébral est plus haut que la face postérieure (Mahadevan, 2018; Waxenbaum et al., 2017). La figure 1.2 illustre l'anatomie générale de la vertèbre lombaire typique.

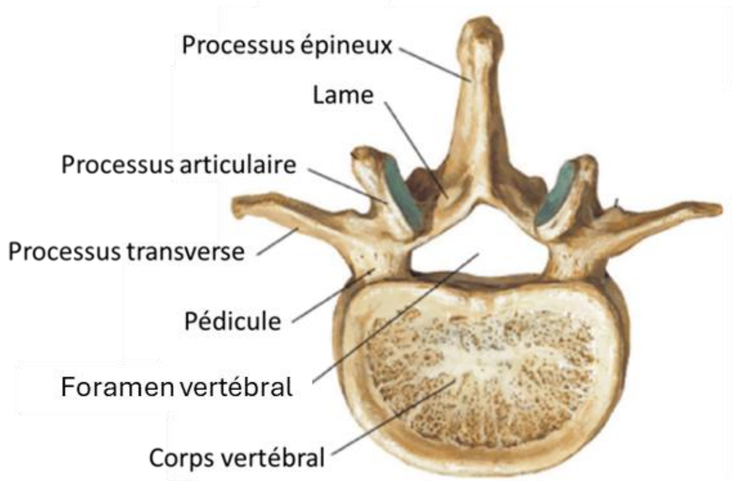

Figure 1.2 - Anatomie générale de la vertèbre lombaire typique

Figure traduite et adaptée de (Bijendra et al., 2018)

1.2 Vieillissement de la colonne lombaire

Comme mentionné en introduction de cette thèse, plusieurs changements physiologiques peuvent être observés au niveau de la colonne lombaire de la personne âgée venant affecter l'intégrité de celle-ci. Ces changements touchent plusieurs structures dont les os et les ligaments, et ce, sur plusieurs segments vertébraux. Les cinq principaux éléments pouvant être affectés par le processus dégénératif de la colonne lombaire sont les disques intervertébraux, les corps vertébraux, les facettes articulaires, le ligament jaune et le ligament longitudinal postérieur (Fehlings et al., 2015; Sąsiadek & Jackow-Nowicka, 2024). Ces changements seront brièvement expliqués dans les prochains paragraphes et l'implication de certains d'entre eux sera davantage détaillée dans la section portant sur la physiopathologie de la SSL qui se trouve dans la section 1.3 de cette thèse.

La dégénérescence des disques intervertébraux se manifeste par une perte de la hauteur discale et engendre un risque de fissures au niveau de l'anneau fibreux qui entoure le noyau. La perte de la hauteur discale peut être engendrée par des mécanismes liés au vieillissement comme les modifications dans la production de collagène et la déshydratation et par l'accumulation de stress mécanique (Oichi et al., 2020). La perte de hauteur discale et la présence de fissures peuvent provoquer une hernie discale à la suite de divers stimuli mécaniques (Scarcia et al., 2022). La dégénérescence discale engendre une redistribution des charges axiales ce qui augmente le stress mécanique sur les éléments postérieurs de la colonne comme les facettes articulaires. Les facettes doivent donc supporter une plus grande portion du poids en plus guider ou contraindre les mouvements des vertèbres (Jaumard et al., 2011). Cette modification crée généralement une inflammation synoviale ainsi qu'une réduction de l'espace articulaire qui entraîne à son tour l'hypertrophie des facettes articulaires, un désalignement apophysaire, une subluxation ainsi que la formation d'ostéophytes (Fehlings et al., 2015). Le vieillissement de la colonne vertébrale s'accompagne aussi d'une diminution de la qualité osseuse. En effet, avec l'âge, le volume d'os qui se forme lors du remodelage devient inférieur au volume d'os résorbé ce qui entraîne une diminution de la masse osseuse de la vertèbre (Seeman, 2013). Avec l'âge, une sclérose des plateaux vertébraux et une ossification de la couche cartilagineuse sus-jacente peuvent se produire (Ferguson & Steffen, 2003). Une formation d'ostéophytes peut aussi se produire sur les corps vertébraux (Fehlings et al., 2015) indiquant ainsi la présence d'arthrose vertébrale (Klaassen et al., 2011).

Avec le vieillissement, le ligament jaune tend à s'hypertrophier et cette hypertrophie s'explique par une perte des fibres élastiques et une augmentation de la proportion du nombre de fibres de collagène qui compose le ligament. Ces changements au niveau des fibres sont considérés comme la principale pathologie associée à l'hypertrophie du ligament jaune. Les mécanismes exacts permettant d'expliquer ces changements fibreux demeurent toutefois incompris à ce jour (Sun et al., 2020). Plusieurs études suggèrent que l'augmentation du stress mécanique, le vieillissement de l’individu (Fukuyama et al., 1995; Safak et al., 2010; Sun et al., 2020), l’obésité et d’autres maladies comme le diabète puissent être à l’origine de ces changements (Sun et al., 2020).

Finalement, le ligament longitudinal postérieur peut s’ossifier avec le vieillissement de l’individu (Fehlings et al., 2015). Cependant, cette modification affecte un nombre moins élevé d’individus avec une prévalence globale entre 0,1 et 1,7% chez les Nord-Américains (Stapleton et al., 2011; Yoshimura et al., 2014).

L’ensemble des modifications présenté ci-dessus ont une chose en commun, soit le potentiel de réduire davantage l’espace disponible pour les structures nerveuses comme la moelle épinière et les racines des nerfs périphériques. En effet, la taille du canal rachidien au niveau lombaire est influencée par une composante mécanique dynamique. Lors de l’extension du tronc, la taille du canal est naturellement diminuée alors que c’est plutôt l’inverse lors de l’adoption d’une posture pencher vers l’avant (flexion lombaire).

1.3 Définition et pathoanatomie de la SSL

La SSL se définit par la diminution de l’espace disponible pour le passage des composantes neurales et vasculaires de la colonne lombaire en raison d’une réduction de la taille du canal vertébral ou des foramens intervertébraux (Genevay & Atlas, 2010; D Scott Kreiner et al., 2013; Tomkins-Lane et al., 2014). La SSL existe sous deux principales formes, soit la forme congénitale et la forme acquise.

La SSL congénitale se caractérise par des modifications anatomiques anormales d’origine congénitale (p. ex., présence de pédicules courts) et elle peut être associée à des troubles du développement de l’individu (Genevay & Atlas, 2010; Lai et al., 2020). La SSL acquise, quant à elle, se caractérise par des changements dégénératifs qui surviennent au niveau du rachis lombaire (Katz et al., 2022). Les causes à la source des différentes formes de la SSL sont présentées dans le tableau 1.1. Comme la SSL acquise de type dégénérative est la forme la plus courante de SSL, seule celle-ci sera abordée et détaillée dans cette thèse.

Type de SSL	Causes
Congénitale/développementale	1. Idiopathique
	2. Achondroplasie
	3. Autres causes : rachitisme hypophosphatémique résistant à la vitamine D, dysraphisme spinal (lipome, myéloméningocèle), syndrome du moustique
Acquise	1. Dégénérative - Spondylolyse - Spondylolisthésis dégénératif - Scoliose dégénérative - Hypertrophie du ligament postérieur longitudinal - Hypertrophie du ligament jaune - Kystes synoviaux intraspinaux
	2. Postopératoire - Laminectomie - Fusion - Fibrose
	3. Traumatique - Laminectomie - Cyphose/scoliose - Fracture (éclats)
	4. Métabolique - Maladie de Cushing - Ostéoporose - Acromégalie - Pseudogoutte - Ostéodystrophie rénale - Hypoparathyroïdie
	5. Squelettique - Maladie de Paget - Spondylarthrite ankylosante - Polyarthrite rhumatoïde - Hyperostose squelettique idiopathique diffuse

Tableau 1.1 - Causes de la SSL d'origine congénitale et acquise

Tableau adapté de Binder et al. (Binder, Schmidt et Weinstein 2002)

La SSL acquise peut toucher le canal central (sténose centrale), les récessus latéraux (sténose latérale) et les foramens intervertébraux (sténose foraminale) (voir figure 1.3) (Genevay & Atlas, 2010). De plus, il est possible qu'un même individu soit aux prises avec une combinaison des différentes formes de sténoses dégénératives (p. ex., sténose centrale et foraminale impliquant le même segment vertébral).

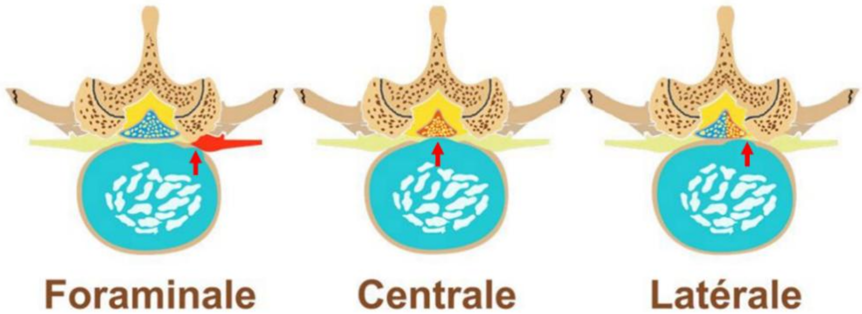

Figure 1.3 - Différents formes de sténose
(Figure inspirée et adaptée de https://www.prodynamicpt.com/blog/2020/5/13/physical-therapy-guide-to-spinal-stenosis et de https://mayfieldclinic.com/pe-sten.htm)

Bien que les trois principales formes de SSL acquise dégénérative (centrale, foraminale et latérale) puissent être classées de manière distincte, elles sont régulièrement regroupées sous une même étiquette, soit celle de la SSL. Toutefois, ce regroupement rend l'interprétation des données probantes existantes plutôt complexes (Lurie & Tomkins-Lane, 2016). Pour cette raison, les trois différentes formes de sténose seront décrites dans cette thèse, mais une attention particulière sera apportée à la sténose centrale comme c'est la forme de sténose d'intérêt identifiée pour les travaux de cette thèse doctorale.

Tout d'abord, la SSL centrale se caractérise par la diminution du canal central du rachis lombaire (Hartvigsen et al., 2018; Lurie & Tomkins-Lane, 2016). Cette diminution s'explique par la diminution du diamètre antéro-postérieur ou du diamètre transversal du canal central, ou encore par une combinaison de ces deux diminutions (Genevay & Atlas, 2010; Steurer et al., 2011) et se produit notamment en raison d'une perte de hauteur discale (avec ou sans bombement du disque intervertébral), de la dégénérescence (présence d'ostéophytes), d'une hypertrophie au niveau des facettes articulaires et de l'hypertrophie du ligament jaune ou par la présence d'un spondylolisthésis (Genevay & Atlas, 2010; Knezevic et al., 2021; Lurie & Tomkins-Lane, 2016). Une telle diminution pourrait également être secondaire à une infection localisée, une blessure traumatique ou une chirurgie (Genevay & Atlas, 2010). La symptomatologie de la LSS centrale est directement associée à la posture de la colonne lombaire (augmentée en position debout prolongée ou avec l'extension du tronc et diminuée avec la flexion du tronc) (Genevay & Atlas, 2010). En effet, tout comme pour les colonnes vertébrales considérées saines, la colonne présentant des signes de dégénérescence ou une sténose est, elle aussi, influencée par le mouvement. Le mouvement d'extension du tronc réduit davantage la taille du canal vertébral comme celui-ci est déjà réduit par les signes de dégénérescences (voir figure 1.4). Les segments vertébraux les plus fréquemment atteints par la SSL centrale sont les suivants : L4-L5, L3-L4, L5-S1 puis L1-L2 (Binder et al., 2002; Knezevic et al., 2021). La sténose centrale peut être accompagnée de douleurs bilatérales bien qu'elles ne soient pas toujours symétriques (Lurie & Tomkins-Lane, 2016). La principale manifestation clinique de la sténose centrale est la claudication neurogène (CN). Cette caractéristique clinique d'importance sera abordée en détails dans la deuxième section de cette thèse.

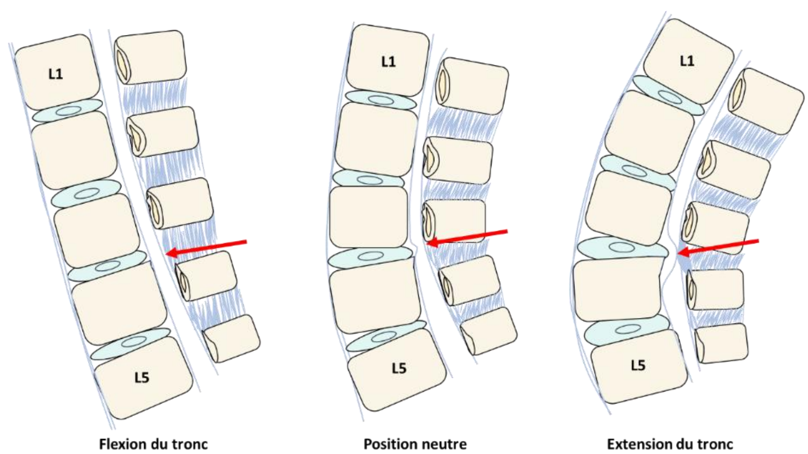

Figure 1.4 - Illustration des modifications anatomiques provoquées par les mouvements de la colonne en présence d'une SSL

Pour la sténose spinale latérale, ce sont sensiblement les mêmes processus pathoanatomiques qui entrent en cause. En effet, la diminution de la hauteur du disque, l'hypertrophie des facettes articulaires avec ou sans présence d'un spondylolisthésis et la présence d'ostéophytes sur les plateaux vertébraux sont également responsables de la sténose spinale latérale (Genevay & Atlas, 2010).

Finalement, la sténose foraminale, décrite comme une réduction de la taille des foramens intervertébraux (Hartvigsen et al., 2018), est causée par la diminution de l'espace discal antéro-postérieur et d’une surcroissance des structures antérieures à la capsule articulaire de la facette. La réduction de la taille des foramens intervertébraux peut également survenir en raison de la présence d’ostéophytes sur les plateaux vertébraux et d’un bombement des anneaux fibreux engendrant une diminution de l’espace verticale ou en raison d’une hernie discale compressant la racine nerveuse contre le pédicule supérieur (Genevay & Atlas, 2010). La sténose foraminale touche plus fréquemment la racine de L5 comme le foramen L5-S1 est l’un des plus petits et que la racine de L5 est la plus grosse racine nerveuse (Rühli et al., 2006). Tout comme pour la sténose centrale, la sténose foraminale possède une composante dynamique qui engendre une diminution d’environ 15% de la superficie du foramen lors de l’extension du tronc comparativement à une augmentation de 12% lors de la flexion (Genevay & Atlas, 2010; Orita et al., 2016).

1.4 Prévalence, incidence et coûts associés à la SSL

1.4.1 Prévalence

Comme introduit précédemment, la SSL est une condition dégénérative du rachis lombaire généralement observée chez les personnes âgées de 50 ans et plus (K. Otani et al., 2013). En raison de l'absence de critères clairs pour l'établissement du diagnostic et la description de la population qui présente des caractéristiques variables, les prévalences instantanées de la SSL rapportées dans différentes régions du monde varient entre 6 % et 47 % (Kalichman et al., 2009). Une méta-analyse récente visant à déterminer l’estimation de la prévalence instantanée de la SSL dans différentes populations (population générale et populations cliniques) indique que la prévalence instantanée basée sur les symptômes cliniques de la SSL est de 11% dans la population générale alors qu’elle varie entre 25% et 39% pour les différentes populations cliniques évaluées (p. ex., consultation en soins primaires et secondaires). La prévalence instantanée basée sur la présence de signes radiologiques associés à la SSL est, pour sa part, de 11% chez les individus asymptomatiques, de 38% dans la population générale alors qu’elle varie entre 15% et 32% pour les populations cliniques. Finalement, la prévalence instantanée de la SSL basée sur la combinaison du diagnostic clinique de la SSL et sur la présence de SSL suite à la réalisation d’IRM varie entre 9% et 56% en fonction de la population évaluée. De manière générale, la prévalence instantanée de la SSL semble augmenter avec l’âge. D'ailleurs, l'augmentation de la prévalence de la SSL semble arriver plus tôt lorsque la décision diagnostique est basée sur les signes radiologiques (vers 40 ans) plutôt que sur le diagnostic clinique (vers 50 ans) (Jensen et al., 2020).

1.4.2 Incidence

Selon une méta-analyse récente, plus de 102 millions d’individus reçoivent un diagnostic de SSL annuellement, ce qui représente une incidence de 1,4%. Cette incidence varie d’un continent à l’autre avec une incidence annuelle moyenne de 0,94% en Afrique et 2,2% en Europe (Ravindra et al., 2018).

1.4.3 Coûts associés à la SSL

Les coûts associés aux soins de santé pour la SSL sont importants. Par exemple, en 2014, le coût moyen associé aux options de traitements médicaux de la SSL s’élevait à environ 7747$ US par patient, et ce, pour une période de 2 ans. Ce coût incluait les coûts directs, c’est-à-dire les coûts liés aux visites médicales, à l’imagerie diagnostique, à la médication et aux injections ainsi que les coûts indirects pouvant notamment être attribués aux journées de travail manquées soit par le patient (Parker et al., 2014). Une étude récente menée par Adogwa et ses collègues indique que les coûts liés à l'utilisation de modalités de traitements non opératoires par les patients atteints de SSL symptomatique ou de spondylolisthésis, qui auront finalement recours à une chirurgie de décompression et de fusion lombaire, s'élèvent à 4010 $ US par patient sur les 5 années précédant l'intervention chirurgicale (Adogwa et al., 2019).

1.5 Évolution naturelle de la SSL

La SSL est une condition neuromusculosquelettique insidieuse dont l’évolution naturelle demeure encore incomprise à ce jour. De manière générale, l’évolution de la SSL est difficilement prévisible et les patients atteints rapportent des périodes au cours desquelles les douleurs sont exacerbées ainsi que des périodes au cours desquelles les douleurs et l’incapacité associées à la condition demeurent plutôt stables (Herno, 2004). Une étude menée en 2016 et impliquant 274 patients traités à l’aide de soins conservateurs sur une période de 3 ans indique que 30,3% des patients présentaient une amélioration subjective des symptômes ressentis alors que 25,4% des patients rapportaient aucun changement des symptômes ou une dégradation des symptômes. Tous les autres participants (44,3%) avaient finalement eu recours à la chirurgie au cours des 3 ans de suivi (Matsudaira et al., 2016). En 2017, Wessberg et Frennered ont tenté de dresser le portrait de l'évolution naturelle des patients ayant un diagnostic de LSS avec des symptômes d'intensité modérée et pour qui la chirurgie n'était pas envisagée. Les 146 patients inclus dans l'étude ont été suivis pendant une durée médiane de 3,3 ans (2,1 à 5,1 ans). Les proportions de patients ayant eu une amélioration, une détérioration ou aucun changement concernant la douleur ressentie dans le bas du dos, dans les jambes et la capacité de marche sont présentées dans la figure 1.5. Considérant ces résultats, les principaux signes et symptômes cliniques associés à la SSL (douleur au dos, douleur au membre inférieur et capacité de marche) sont demeurés inchangés ou se sont améliorés pour la grande majorité des patients. Les résultats d'une étude réalisée par Minamide et ses collègues corroboraient ces observations rapportant des changements favorables de la condition chez près du tiers des patients, aucun changement chez environ 30% des patients et une détérioration de la condition chez près de 30% également (Minamide et al., 2013). Ainsi, l'évolution naturelle favorable de la condition semble offrir une fenêtre de temps intéressante pendant laquelle les patients pourraient bénéficier de soins conservateurs.

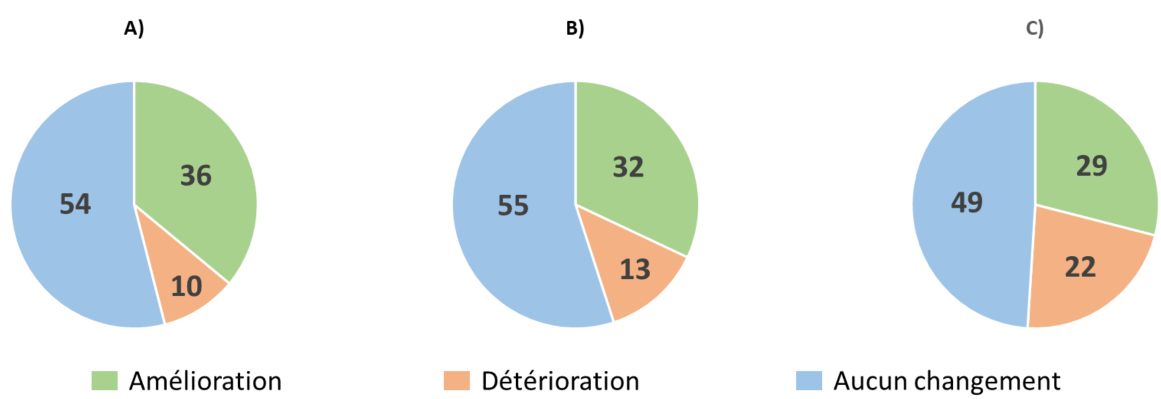

Figure 1.5 - Histoire naturelle de la SSL

Pourcentage (%) de patients pour lesquelles l'histoire naturelle de la SSL engendre une amélioration, une détérioration ou aucun changement pour A) le niveau de douleur au dos mesuré avec une échelle visuelle analogue (ÉVA) allant de 0 à 100 mm, B) le niveau de douleur aux jambes mesurées avec une ÉVA allant de 0 à 100 mm et C) la capacité de marche mesurée avec une échelle catégorielle en fonction de la distance parcourue (catégories = <100 mètres, 100-500 mètres, 500 mètres à 1km et > 1km).

Figure traduite et adaptée de Wessberg et Frennered 2017 (Wessberg & Frennered, 2017)

2. La claudication neurogène (CN)

2.1 Définition et symptômes

La CN représente la principale manifestation clinique de la SSL (Lurie & Tomkins-Lane, 2016; Messiah et al., 2019). Elle se définit comme une démarche asymétrique dont l'origine peut être diverse. L'origine de la claudication peut être soit vasculaire ou neurogène (Nadeau et al., 2013). Dans le cadre de la présente thèse, c'est la claudication d'origine neurogène impliquée dans la SSL qui sera mise de l'avant.

Le terme « claudication » est couramment utilisé pour décrire une difficulté à la marche en raison de douleurs ou de faiblesses des membres inférieurs qui engendrent une boiterie (Larousse, 2024). Reconnu comme un syndrome clinique, la CN est fréquemment associée à des douleurs et à des inconforts (Katz & Harris, 2008). En plus de la douleur, les symptômes associés à la CN sont caractérisés par la présence de fatigue, de crampes, de paresthésies, de picotements, d'engourdissements, de faiblesses de même que par des sensations de lourdeurs et des changements sensoriels dans la région de la fesse ou de la jambe (cuisse, mollet, pied) (Comer et al., 2009; Genevay & Atlas, 2010; Katz & Harris, 2008; Porter, 1996). Ces symptômes peuvent être ressentis de manière unilatérale ou bilatérale. Lorsque les symptômes sont ressentis de manière bilatérale, ils ne sont pas nécessairement ressentis de la même manière ou selon la même intensité dans les deux membres inférieurs (Genevay & Atlas, 2010; Katz et al., 2022; Lurie & Tomkins-Lane, 2016). Chez les patients ayant un diagnostic de SSL, la CN se manifeste généralement lors de la station debout prolongée et lors d'activités comme la marche (Genevay & Atlas, 2010). De façon générale, l'arrêt de l'activité engendrant les douleurs ou les inconforts et l'adoption d'une position de repos comme la position assise ou accroupie permettent de soulager le patient (Genevay & Atlas, 2010; Munakomi et al., 2024). De plus, la marche en pente positive (p. ex., monter la rue, monter les escaliers) est plus confortable que la marche dans une pente négative (p. ex., descendre la rue, descendre les escaliers)(Genevay & Atlas, 2010). En effet, le changement de posture permettant le soulagement des symptômes est l'un des principaux éléments permettant de distinguer la claudication d'origine neurogène d'autres types de claudication comme la claudication d'origine vasculaire (Genevay & Atlas, 2010; Lurie & Tomkins-

Lane, 2016). Plus précisément, la CN est exacerbée par la position d'extension de la colonne lombaire (diminution de la cyphose thoracique et augmentation de la lordose lombaire) alors qu'elle est généralement soulagée par la flexion du tronc (augmentation de la cyphose thoracique et diminution de la lordose lombaire) (Genevay & Atlas, 2010; Messiah et al., 2019). Ce phénomène de soulagement par la flexion du tronc est régulièrement nommé « signe du panier d'épicerie ». En effet, les patients présentant une SSL avec CN ont tendance à utiliser le panier disponible lors des courses (p. ex., à l'épicerie ou dans les magasins à grande surface) afin de s'y appuyer et d'ainsi adopter une légère flexion du tronc. L'adoption d'une telle posture est caractéristique de la condition et leur permet de poursuivre la tâche en cours tout en limitant les symptômes (p. ex., la marche) (Houle et al., 2021; Penning, 1992). Lors de la marche libre, les patients ayant un diagnostic de LSS avec CN tendent à fléchir légèrement le tronc ou à se pencher en plus de modifier leur patron de marche afin d'améliorer leur tolérance à la marche. Il est cependant à noter que le soulagement des symptômes est temporaire et qu'une période de repos est souvent nécessaire.

2.2 Pathophysiologie de la CN

Bien que les impacts de la posture sur les symptômes associés à la claudication neurogène (CN) et les mécanismes les expliquant ne soient pas encore tout à fait compris, les données probantes actuelles suggèrent que les variations des symptômes cliniques présentes dans la CN résulteraient de changements sténotiques. Ces changements sténotiques sont des variations de la taille du canal central vertébral qui surviennent lors de changements posturaux, par exemple, la diminution de la taille du canal central lors de l'extension du tronc. En effet, un rétrécissement de la taille du canal central vertébral induit une compression qui entraîne des atteintes neurales et microvasculaires au niveau des racines nerveuses de la queue de cheval et lombosacrées. Les deux modèles explicatifs prédominants expliquant l'origine des symptômes associés à la CN, sont le modèle de l'ischémie et celui de la stase veineuse, qui reposent tous deux, dans une certaine mesure, sur la compression mécanique des structures nerveuses et vasculaires lors de l'adoption de postures favorisant l'extension de la colonne lombaire (extension du tronc) (Kobayashi, 2014; Lurie & Tomkins-Lane, 2016). Plus particulièrement, le modèle explicatif de l'ischémie stipule qu'une compression au niveau de la microvascularisation provoquerait une ischémie des racines nerveuses notamment celles de la queue de cheval. Cette ischémie serait responsable de la diminution de l'apport sanguin dans les racines nerveuses ciblées. Autrement dit, il y aurait une diminution de la possibilité de vasodilatation des artères responsables d'acheminer les nutriments au(x) nerf(s) affecté(s) (Binder et al., 2002; Deer et al., 2019; Fritz et al., 1998; Gandhi et al., 2018; Lurie & Tomkins-Lane, 2016). Le modèle explicatif de la stase veineuse, quant à lui, suggère qu'il y aurait une compression des veines se situant à proximité de la colonne vertébrale ce qui pourrait entraîner une rétention du sang dans les vaisseaux sanguins. Le flux normal vers les racines nerveuses serait donc perturbé (oxygénation inadéquate) et il y aurait une accumulation de métabolites. La rétention causerait également une accumulation de liquide et serait à l'origine d'une hausse de la pression (Binder et al., 2002; Gandhi et al., 2018; Katz et al., 2022; Lurie & Tomkins-Lane, 2016). D'autres modèles explicatifs comme celui stipulant la présence d'une altération du liquide cérébrospinal ou celui sur le rôle de l'inflammation ont été mis de l'avant par des chercheurs pour expliquer les symptômes associés à la CN, mais ces modèles demeurent des hypothèses. En 2021, Kim et ces collègues ont montré que les paramètres dynamiques du liquide cérébrospinal seraient associés à la sévérité des symptômes de la SSL (Kim et al., 2021). Finalement, l'hypothèse concernant le processus inflammatoire aigu n'a, jusqu'à présent, montré aucune donnée probante assez robuste pour être retenue afin d'expliquer les symptômes associés à la CN (Genevay & Atlas, 2010).

3. Diagnostic clinique de la SSL avec CN

À ce jour, il n'existe pas d'outils de mesure standardisés permettant le diagnostic clinique de la SSL. Les preuves scientifiques indiquent plutôt qu'une combinaison de critères subjectifs et objectifs doit être considérée afin d'établir un diagnostic clinique de SSL avec CN. Ces critères comprennent les informations pertinentes associées à l'histoire médicale du patient, l'examen physique réalisé par le professionnel de la santé et les résultats issus de l'imagerie médicale (Deer et al., 2019; Knezevic et al., 2021; Lurie & Tomkins-Lane, 2016; Tomkins-Lane et al., 2014).

3.1 Histoire médicale

Les informations recueillies auprès des patients comme les signes et symptômes font partie intégrante du processus menant au diagnostic clinique de la SSL. Plus particulièrement, les informations importantes suggérant une possible SSL sont les suivantes : être âgé de plus de 48 ans, avoir une douleur irradiant dans la ou les jambes qui se trouve exacerbée lors de la station debout prolongée ou lors de la marche et qui est soulagée avec l'adoption de postures favorisant la flexion du tronc (p. ex., se pencher vers l'avant ou s'asseoir), avoir des douleurs plus importantes au niveau du membre inférieur plutôt qu'au niveau du bas du dos et ne pas présenter de douleur en position assise (Cook et al., 2020; de Schepper et al., 2013; Deer et al., 2019; Katz et al., 2022; Knezevic et al., 2021). D'autres éléments permettant d'identifier la présence de CN comme le signe du panier d'épicerie positif sont également des éléments importants de l'histoire médicale rapportée par le patient (Katz et al., 2022; Lurie & Tomkins-Lane, 2016; Nadeau et al., 2013).

3.2 Examen physique

Concernant l'examen physique, il existe plusieurs éléments quantifiables ou observables pouvant contribuer à la prise de décision clinique quant au diagnostic de la SSL. En 2020, un groupe de travail portant sur le diagnostic clinique de la SSL a déterminé par consensus que l'examen physique devait minimalement comprendre un examen neurologique complet incluant les tests de tension nerveuses et une évaluation de la marche avec observation du patron de marche (Tomkins-Lane et al., 2020). En effet, un tel examen physique permet, entre autres, d'évaluer la distance ou le temps de marche total (capacité de marche) des patients en fonction notamment de la posture de marche (dos bien droit ou flexion lombaire) et d'observer s'il y a une augmentation de la base de support lors de la marche ou un patron de marche dit « anormal » (Cook et al., 2020; de Schepper et al., 2013; Knezevic et al., 2021; Tomkins-Lane et al., 2020).

D'autres tests permettant d'identifier une diminution de la mobilité lombaire, particulièrement en extension du tronc, la présence de muscles ischio-jambes très tendus, la diminution de la proprioception et de l'équilibre de même que des faiblesses musculaires au niveau des membres inférieurs et une diminution des réflexes des nerfs ciblés peuvent également être utilisés pour compléter l'examen physique (Cook et al., 2020; de Schepper et al., 2013; Deer et al., 2019; Genevay & Atlas, 2010; Knezevic et al., 2021; D. S. Kreiner et al., 2013).

Enfin, d'autres tests permettant la classification de la CN peuvent aussi être utilisés. En effet, une récente étude de Genevay et ses collègues indique qu'un résultat positif au test d'extension active du rachis lombaire effectuée en position debout pendant 30 secondes et un résultat négatif au test d'élévation de la jambe tendue à 60 degrés en combinaison avec les symptômes rapportés par les patients (douleur aux jambes qui s'atténue avec la flexion du tronc vers l'avant et la position assise) permettent d'identifier la CN associée à la SSL (Genevay et al., 2018). Lors de l'examen physique, il est aussi important d'exclure la possibilité que les symptômes soient associés à d'autres conditions de santé. La CN présente chez les patients ayant un diagnostic de SSL est semblable à la claudication que l'on peut retrouver chez les patients ayant un diagnostic de maladie artérielle périphérique (MAP). L'origine de cette claudication étant vasculaire, il est donc important d'inclure des tests permettant d'évaluation la symétrie des pouls au niveau du pied de même que le ratio entre la pression systolique mesurée à la cheville et celle mesurée au niveau du bras (Indice tibio-brachial : ITB) (Tomkins-Lane et al., 2020). Les auteurs suggèrent aussi d'effectuer des tests permettant d'éliminer la possibilité que les douleurs proviennent de troubles à la hanche ou même d'une myélopathie cervicale (Tomkins-Lane et al., 2020).

3.3 Imagerie

Lorsque l'histoire médicale et l'examen physique suggèrent une SSL avec CN, il est important d'en confirmer la présence et l'emplacement exact à l'aide de techniques d'imagerie médicale. Bien que l'imagerie par résonnance magnétique (IRM) soit le type d'imagerie à privilégier en raison de sa capacité à distinguer les tissus mous comme les disques, les muscles, le cartilage, les racines nerveuses et les ligaments, d'autres techniques d'imagerie comme la tomodensitométrie (CT-scan) ou la myélographie sont utilisées pour confirmer le diagnostic de SSL. En effet, les données probantes actuelles suggèrent de choisir le type d'imagerie à utiliser en fonction de la condition de santé globale du patient (Katz et al., 2022; Knezevic et al., 2021; Lurie & Tomkins-Lane, 2016; Tomkins-Lane et al., 2020). En ce sens, si aucune contre-indication n'est présente chez le patient, l'IRM devrait être le premier choix d'imagerie (Katz et al., 2022). De plus, il est préférable d'éviter l'utilisation de la myélographie en raison de sa nature plus invasive et de sa plus faible précision (de Schepper et al., 2013).

Les paramètres objectifs les plus souvent rapportés et basés sur la définition anatomique de la SSL centrale lors de l'analyse en imagerie médicale comme l'IRM sont la présence d'un diamètre antéro-postérieur de moins de 10 mm et une surface transversale de moins de 70 mm^2 du canal spinal (Lurie & Tomkins-Lane, 2016; Steurer et al., 2011). Récemment, une étude a montré que les critères objectifs pour la SSL obtenus à l'IRM avec une coupe axiale T2 pondérée doivent montrer une section transversale du canal central inférieure à 191 mm ou une surface de section transversale du canal central inférieure à 147 mm (Lim et al., 2017). Du côté de l'analyse qualitative de l'imagerie, c'est plutôt la présence d'une protrusion du disque qui est à vérifier (Mamisch et al., 2012).

Dans certains cas, des tests supplémentaires peuvent être nécessaires pour évaluer la présence d'une SSL centrale. En effet, l'électromyographie ou le test de vitesse de conduction nerveuse peuvent être utilisés pour assurer la discrimination clinique de la SSL centrale par rapport à d'autres conditions de santé pouvant engendrer des symptômes similaires (p. ex., claudication vasculaire, arthrose symptomatique de la hanche) (de Schepper et al., 2013; Lurie & Tomkins-Lane, 2016).

Bien que les symptômes de la SSL et de la CN soient bien identifiés, il reste, à ce jour, quelques zones grises quant aux mécanismes qui leur sont propres, influençant par le fait même les critères diagnostiques utilisés. Cette réalité est d'autant plus importante puisque plusieurs formes de sténose (p. ex., centrale et foraminale) peuvent être présentes chez un même individu et qu'il est possible qu'une MAP soit également présente chez cet individu. Ainsi, il demeure complexe de diagnostiquer la SSL avec CN.

4. Capacité de marche et CN

Les symptômes associés à la SSL et, plus particulièrement, la CN, jouent un rôle majeur dans le déclin des capacités physiques fonctionnelles des patients. Lorsqu'il est question de capacités physiques fonctionnelles, la marche est considérée comme une activité importante qui influence directement la mobilité et l'indépendance de l'individu (World Health Organization, 2024). Elle est d'ailleurs l'activité la plus impactée par la CN chez les patients ayant un diagnostic de SSL (Fritz et al., 1998). Selon les données probantes les plus récentes, les patients aux prises avec une CN auraient des limitations à la marche plus importantes que les individus souffrant d'arthrose symptomatique aux genoux ou aux hanches (Winter et al., 2010). En plus de réduire significativement la mobilité des patients, la CN est également associée à une diminution de la participation aux activités sociales, à des répercussions négatives sur la santé psychologique et la santé émotionnelle ainsi qu'à une fragilité accrue et une perte d'indépendance chez les individus atteints (Griffiths et al., 2022). Ensemble, ces éléments contribuent à la diminution de la qualité de vie des patients ayant un diagnostic de SSL avec CN. Il est également important de noter que le déclin de la capacité de marche et les effets négatifs sur la santé émotionnelle sont considérés comme les conséquences les plus significatives par les patients ayant un diagnostic de SSL avec CN (C. Ammendolia et al., 2017).

Comme la capacité de marche est au cœur des préoccupations des patients et qu'elle représente un élément important quant au maintien des capacités physiques fonctionnelles et de l'indépendance de l'individu, celle-ci sera au cœur des études présentées dans cette thèse doctorale. Les prochains paragraphes permettront de mieux définir la capacité de marche et de mieux comprendre comment la mesurer. Puis, la section 5 de cette thèse abordera le patron de marche et mettra en évidence les modifications observables dans le patron de marche qui sont attribuables au vieillissement et ceux qui caractérisent la SSL avec CN.

4.1 Définition de la capacité de marche

D'abord, il est important de bien comprendre ce que représente la capacité de marche. Selon la Classification internationale du fonctionnement, de l'incapacité et de la santé (*International Classification of Functioning, Disability and Health*: ICF), deux termes fréquemment utilisés soit la capacité et la performance doivent être distingués. Le terme « capacité » désigne ce qu'un individu est capable de faire dans un environnement standardisé (p. ex., évaluation clinique), alors que la performance désigne ce que la personne est capable de réaliser dans son environnement habituel (p. ex., à la maison) (World Health Organization, 2001). Comme les données probantes existantes proviennent d'essais cliniques et que les études incluses dans cette thèse doctorale s'inscrivent dans une perspective clinique, c'est le terme « capacité de marche » qui sera utilisé pour le reste de cette thèse.

4.2 Évaluation de la capacité de marche

Tel que mentionné précédemment, la capacité de marche est une composante essentielle à la fois pour le diagnostic de la SSL avec CN et pour le suivi des patients. D'ailleurs, plusieurs questionnaires, tests standardisés (évaluation en laboratoire ou en clinique) et tests réalisés en milieu de vie ont jusqu'à maintenant été utilisés pour mesurer cette capacité de marche (Conway et al., 2011). Comme la présente thèse s'inscrit dans une perspective clinique et que les cliniciens ont besoin d'évaluations standardisées pouvant être facilement reproductibles, seul le test *Self-Paced Walking Test* (SPWT) sera pris en considération dans cette section.

Le SPWT est le test de marche standardisé le plus utilisé à ce jour pour l'évaluation de la capacité de marche des patients ayant un diagnostic de SSL. Dans le cadre de ce test, les patients doivent marcher sur une surface plane à leur propre rythme, et ce, sans utiliser d'aide à la marche. Le test prend fin lorsque les patients sont dans l'obligation de s'arrêter en raison des symptômes associés à la SSL ou jusqu'à ce qu'ils atteignent la durée de marche limite fixée à 30 minutes. Pour qu'un arrêt soit considéré, celui-ci doit durer au moins 3 secondes. Les patients sont également invités à signaler le moment où ils ressentent une modification dans leurs symptômes. Pendant toute la durée du test, l'évaluateur doit se tenir à environ un mètre derrière le patient en évitant de faire la conversation. Le SPWT vise à reproduire des conditions de marche réelles en utilisant un cadre standardisé (Tomkins-Lane et al., 2009). Ce test clinique possède une reproductibilité autant pour la distance de marche totale que pour la distance de marche avant l'apparition des premiers symptômes chez les patients ayant un diagnostic de SSL avec CN ainsi qu'une excellente validité (Tomkins-Lane et al., 2009).

Ce test est régulièrement utilisé comme mesure de critère par les chercheurs. D'ailleurs, une récente revue systématique avec méta-analyse recommandait aux chercheurs et aux cliniciens d'utiliser le SPWT pour l'évaluation de la capacité de marche des patients présentant une claudication neurogène. Cette même revue soulève toutefois le manque de données probantes de haute qualité obtenues avec de grandes tailles d'échantillon ce qui ne permet pas de confirmer le test comme un standard étalon (Anderson et al., 2019).

En somme, la diminution de la capacité de marche demeure l'une des conséquences phares de la SSL avec CN et elle peut facilement être mesurée en clinique. Cependant, l'évaluation de la capacité de marche ne permet pas de comprendre les enjeux potentiels sur le plan biomécaniques. Une meilleure connaissance des impacts de la SSL avec CN sur la biomécanique à la marche, plus particulièrement sur les paramètres du patron de marche pouvant être mesurés dans un espace clinique permettrait de mieux déterminer les paramètres optimaux à inclure dans un plan de réadaptation physique.

5. Conséquences de la SSL avec CN sur la biomécanique à la marche

Bien qu'il soit clair que la capacité de marche des patients ayant un diagnostic de SSL avec CN soit impactée, les conséquences exactes de la condition sur le patron de marche des patients restent encore à déterminer. Généralement, les études réalisées auprès des les patients ayant un diagnostic de SSL avec CN s'intéressent davantage à la capacité de marche compte tenu de l'importance de cette dernière dans le processus diagnostic et dans la prise en charge. Il serait donc intéressant de pouvoir combiner l'évaluation des paramètres de la marche et la capacité de marche dans une même étude et potentiellement identifier les paramètres ayant un lien direct avec la capacité de marche.

Les patients ayant un diagnostic de SSL avec CN sont généralement âgés et les paramètres biomécaniques que l'on retrouve dans le patron de marche peuvent donc être influencés à la fois par le processus de vieillissement et la SSL avec CN. Ainsi, il est important de bien comprendre les effets de l'âge sur les paramètres du patron de marche pour ensuite être en mesure d'identifier les déviations du patron de marche qui sont attribuables à la SSL avec CN.

5.1 Patron de marche – généralités

Chez l'adulte en bonne santé, la marche est une activité fluide qui intègre des dynamiques complexes de balancement, d'absorption des chocs et de propulsion, en plus des signaux du système nerveux central, pour assurer une locomotion efficace. La marche est une activité cyclique qui fait intervenir des séquences de mouvements répétées pour propulser le corps vers l'avant et maintenir la stabilité de la posture (Perry & Burnfield, 2024). Lors de l'entièreté du cycle de marche, l'individu reste en contact avec le sol et les membres inférieurs gauche et droit oscillent en alternance (Whittle, 2014). Le cycle de marche se définit comme l'intervalle de temps séparant deux contacts consécutifs d'un même événement de la marche (p. ex., contact du talon avec le sol du pied gauche) (Whittle, 2014). Il se divise en deux grandes phases, soit la phase d'appui (environ 0-60% du cycle de marche) et la phase d'oscillation (environ 60 à 100% du cycle de marche). La phase d'appui représente le moment où le membre inférieur est en contact continu avec le sol alors que la phase d'oscillation représente le moment où le membre inférieur n'est plus en contact avec le sol et qu'un mouvement de balancier du pied s'observe afin de préparer le pied au prochain contact (Kharb et al., 2011; Perry & Burnfield, 2024; Whittle, 2014). Dès qu'il y a un nouveau contact du membre inférieur au sol, c'est une nouvelle phase d'appui qui débute. Lors de la phase d'appui, il existe de courts moments où les membres inférieurs droit et gauche se trouvent au sol en même temps. Cette phase secondaire se nomme la phase de double appui et se produit au début et à la fin de la phase d'appui (Perry & Burnfield, 2024). La figure 1.6 illustre le cycle de marche d'un adulte n'ayant pas de douleur à la marche.

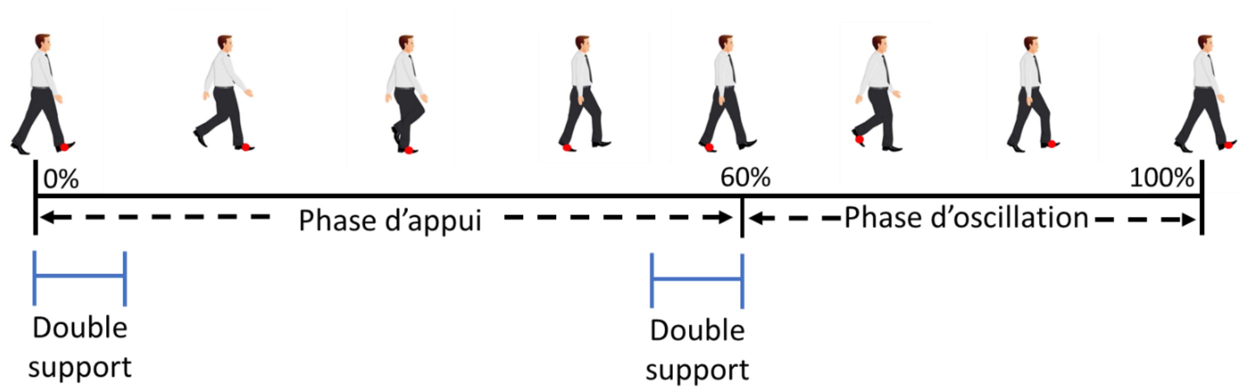

Figure 1.6 - Cycle de marche

Les deux grandes phases du cycle de marche (phase d'appui et phase d'oscillation) peuvent être subdivisées à leur tour en différentes sous-phases. L'utilisation de telles sous-phases permet notamment l'analyse du patron de marche de manière plus précise puisque ces sous-phases sont déterminées en fonction des mouvements du membre inférieur évalué. Selon une revue systématique publiée en 2016, la phase d'appui peut être composée de deux à huit sous-phases alors que la phase d'oscillation peut être composée d'un maximum de trois sous-phases (Taborri et al., 2016)(voir le tableau 1.2).

<table>
<tr><th>Nombre de phases</th><th colspan="14">Subdivision du cycle de marche</th></tr>
<tr><td>2</td><td colspan="10">Phase d’appui</td><td colspan="4">Phase d’oscillation</td></tr>
<tr><td>3</td><td>Premier basculement</td><td colspan="9">Second basculement</td><td colspan="4">Phase d’oscillation</td></tr>
<tr><td>4</td><td colspan="3">Attaque du talon</td><td colspan="4">Pied à plat</td><td colspan="3">Décollement du talon</td><td colspan="4">Phase d’oscillation</td></tr>
<tr><td>5</td><td colspan="2">Attaque du talon</td><td colspan="3">Pied à plat</td><td colspan="3">Décollement du talon</td><td colspan="2">Décollement des orteils</td><td colspan="4">Phase d’oscillation</td></tr>
<tr><td>6a</td><td>Contact initial</td><td colspan="3">Mise en charge</td><td colspan="2">Appui intermédiaire</td><td colspan="3">Appui terminal</td><td>Pré-oscillation</td><td colspan="4">Phase d’oscillation</td></tr>
<tr><td>6b</td><td colspan="2">Mise en charge</td><td colspan="3">Appui intermédiaire</td><td colspan="3">Appui terminal</td><td colspan="2">Pré-oscillation</td><td colspan="2">Oscillation 1</td><td colspan="2">Oscillation 2</td></tr>
<tr><td>7</td><td colspan="2">Mise en charge</td><td colspan="3">Appui intermédiaire</td><td colspan="3">Appui terminal</td><td colspan="2">Pré-oscillation</td><td>Oscillation initiale</td><td colspan="2">Oscillation intermédiaire</td><td>Oscillation terminale</td></tr>
<tr><td>8</td><td>Contact initial</td><td colspan="3">Mise en charge</td><td colspan="2">Appui intermédiaire</td><td colspan="3">Appui terminal</td><td>Pré-oscillation</td><td>Oscillation initiale</td><td colspan="2">Oscillation intermédiaire</td><td>Oscillation terminale</td></tr>
</table>

Tableau 1.2 - Subdivision des phases du cycle de marche (traduit et adapté de Taborri et al. 2016)

De manière générale, la subdivision des phases du cycle de marche est réalisée à l'aide de technologies variées comme les semelles de pression plantaire et les capteurs inertiels. Selon la revue systématique de Taborri et ses collègues, le choix du nombre de sous-phases à évaluer doit être fait en fonction de l'objectif visé lors de l'évaluation du cycle de marche. Par exemple, lors de l'évaluation de cycle de marche chez des individus ayant une pathologie, le nombre de sous-phases déterminées pourrait être plus élevé afin de mieux identifier la sévérité de ces pathologies. De plus, le choix de l'outil de mesure devrait être fait en fonction du nombre de sous-phases que l'on souhaite évaluer (Taborri et al., 2016). L'usage de technologies portables comme les capteurs inertiels semble donc intéressant pour identifier les modifications des différents paramètres de marche. Ces capteurs permettraient de subdiviser notamment la phase d'appui et ainsi de mieux comprendre les impacts de la condition sur les différents paramètres spatio-temporels et de dégagement du pied et des orteils que l'on retrouve dans le patron de marche. De plus, ces capteurs portatifs permettent l'évaluation standardisée de la marche dans des milieux cliniques plus restreints. Les prochaines sous-sections présenteront donc les modifications du patron de marche attribuables au vieillissement puis les modifications attribuables à la SSL avec CN chez le patient âgé.

5.2 Influence du vieillissement sur le patron de marche

Chez l'adulte en bonne santé et sans douleur, la marche est une activité motrice complexe considérée comme automatique (Clark, 2015). Toutefois, cet automatisme s'estompe graduellement avec le vieillissement de l'individu (Reimann et al., 2020).

Les changements physiologiques et psychologiques associés au processus de vieillissement sont à l'origine de différentes modifications du patron de marche excepté pour la cadence qui semble demeurer stable avec l'avancée en âge (McKay et al., 2017). De manière générale, les plus récentes données probantes indiquent que le vieillissement engendre une diminution de la vitesse de marche (Bohannon & Andrews, 2011; McKay et al., 2017; Morfis & Gkaraveli, 2021; Sloot et al., 2021), une diminution de la longueur de pas (McKay et al., 2017; Morfis & Gkaraveli, 2021) et une diminution de la longueur de la foulée (Morfis & Gkaraveli, 2021) alors que le temps passé en double appui serait, quant à lui, augmenté (McKay et al., 2017). Les résultats d'une étude ayant mesuré d'autres paramètres de marche indiquent que le vieillissement est associé à une plus grande variabilité de la marche, à une longueur de pas et de foulée plus courte, à une diminution de la vitesse de marche, à une augmentation du temps associé à la phase d'appui et au double appui, à une diminution de la largeur de la foulée avec une augmentation de la variabilité de la largeur de la foulée (Verlinden et al., 2013).

Si l'on s'intéresse davantage à la vitesse de marche, les résultats d'une méta-analyse réalisée auprès d'adultes âgés entre 20 et 89 ans sans pathologie indiquent que celle-ci diminue avec le vieillissement, et ce, à la fois chez la femme et chez l'homme (voir tableau 1.3). Chez les individus âgés entre 20 ans et 69 ans, la vitesse reste relativement stable et le déclin de la vitesse de marche semble s'observer à partir de l'âge de 70 ans (Bohannon & Andrews, 2011). Plus récemment, les résultats de McKlay et ses collègues ont montré que la vitesse de marche moyenne pour les hommes âgés de 20 à 59 ans est de 130,9 ± 15,0 cm/s, tandis que pour les hommes de 60 ans et plus, elle est plutôt de 119,7 ± 17,5 cm/s. Une réduction similaire de la vitesse de marche a été observée chez les femmes, avec une vitesse de 133,1 ± 14,6 cm/s pour les femmes âgées de 20 à 59 ans et de 117,1 ± 21,8 cm/s pour celles de 60 ans et plus (McKay et al., 2017). Les résultats de l'étude de Sloot et ses collègues publiée en 2019, abondent dans le même sens. En effet, les résultats indiquent que les adultes âgés entre 20 et 29 ans ont une vitesse de marche de 1,21 ± 0,04 m/s alors que cette vitesse passe à 1,06 ± 0,04 m/s (hommes et femmes confondus) chez les personnes âgées entre 80 et 89 ans (Sloot et al., 2021).

	Vitesse moyenne de marche (cm/seconde) (95% CI)	
Âge	**Hommes**	**Femmes**
20 à 29 ans	135.8 (121.7 – 147.4)	134.1 (108.2 – 149.9)
30 à 39 ans	143.3 (132.0 – 153.8)	133.7 (125.6 – 141.5)
40 à 49 ans	143.4 (127.0 – 147.0)	139.0 (122.0 – 142.0)
50 à 59 ans	143.3 (112.2 – 149.1)	131.3 (110.0 – 155.5)
60 à 69 ans	133.9 (103.3 – 159.0)	124.1 (97.0 – 145.0)
70 à 79 ans	126.2 (95.7 – 141.8)	113.2 (83.0 – 150.0)
80 à 89 ans	96.8 (60.8 – 122.1)	94.3 (55.7 – 117.0)

Tableau 1.3 - Vitesse moyenne de marche des hommes et des femmes par groupe d'âge *(Tableau tiré et adapté de Bohannon and Andrews, 2011).*

Depuis plusieurs années, les études s'intéressant aux populations âgées portent une attention particulière à la vitesse de marche. Cette attention croissante pour la vitesse de marche s'explique par le fait que la vitesse de marche est une variable importante pour la prévention des risques de chutes chez la personne âgée (Pamoukdjian et al., 2015). Récemment, le groupe de travail de l'Académie Internationale sur la Nutrition et le Vieillissement a tenté, par le biais d'une revue systématique et d'un panel de discussion composé d'experts, d'évaluer si la vitesse de marche, mesurée à un rythme de marche usuel sur une courte distance, peut identifier les personnes âgées autonomes vivant dans la communauté et à risque de résultats cliniques défavorables. Ce groupe de travail a permis de mettre en évidence l'importance de la vitesse de marche comme prédicteur indépendant des chutes chez la personne âgée considérée en bonne santé (Abellan van Kan et al., 2009). Ce groupe de travail a également mis de l'avant les valeurs seuils de la vitesse de marche obtenues lors d'évaluation à vitesse usuelle et les risques de résultats cliniques défavorables associés à la vitesse de marche issues des données probantes existantes. Ces valeurs seuils sont présentées dans la figure 1.7. En considérant ces valeurs seuils, une autre équipe de recherche a pu mettre en évidence la présence d'une relation non-linéaire entre la vitesse de marche et le nombre de chutes. Le risque de chute semble donc plus élevé chez les personnes âgées marchant lentement (<0,6 m/s) ou marchant rapidement (>1,3 m/s) que chez les personnes âgées pour qui la vitesse de marche est moyennement anormale (>0,6 m/s, mais <1,0 m/s) ou normale (>1,0 m/s, mais <1,3 m/s) (Quach et al., 2011). D'autres études publiées récemment ont également reconnu l'usage d'une vitesse de marche lente comme un facteur prédictif et un indicateur de divers troubles, tels que les chutes, les troubles cognitifs, le déclin fonctionnel et la mortalité chez les personnes âgées. (Kyrdalen et al., 2019; Mielke et al., 2013; Stanaway et al., 2011).

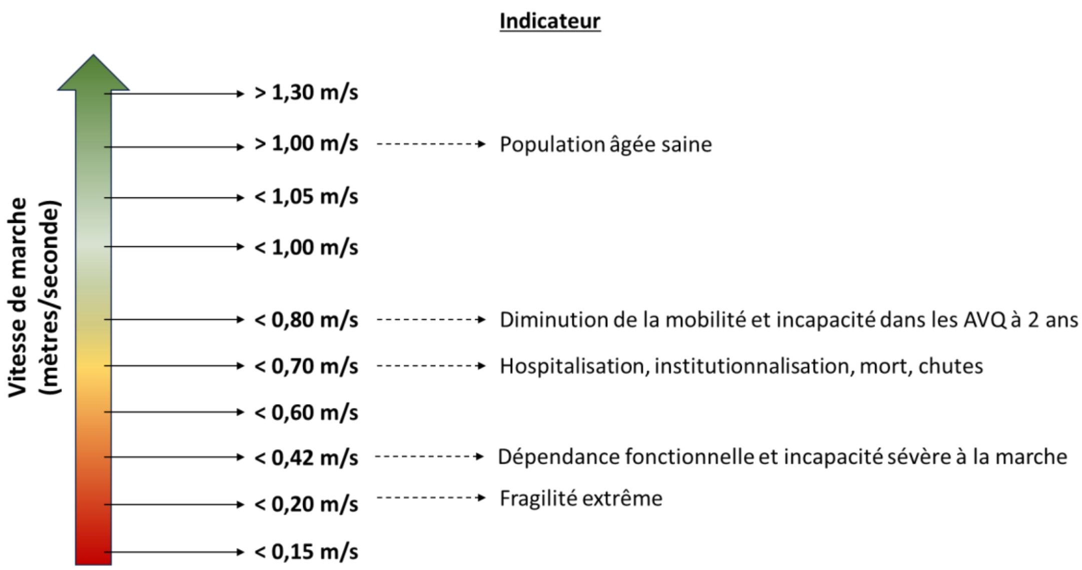

Figure 1.7 - Valeur seuil de la vitesse de marche et risques de résultats cliniques défavorables associés

(Tirée, adaptée et traduite de Abellan van Kan et al., 2009)

Un autre paramètre clé du patron de marche impliqué dans la prévention des chutes est la mesure du dégagement minimal du pied. Ce paramètre se définit comme la distance verticale entre le point le plus bas du pied de la jambe oscillante et la surface de marche lors de la moitié du balancement (Winter, 1991). Généralement, le dégagement minimal du pied varie entre 10 et 20 mm (Barrett et al., 2010; Winter, 1991). Selon les résultats d'une revue systématique, ce paramètre du patron de marche ne semble pas affecté par l'âge (Barrett et al., 2010). Il y aurait toutefois une plus grande variabilité des valeurs du dégagement minimal du pied chez les personnes âgées (Barrett et al., 2010). Bien que les mécanismes expliquant cette variabilité soient encore incertains, l’une des hypothèses mise de l’avant est que la sensibilité proprioceptive et la capacité à moduler une force musculaire serait réduite chez les personnes âgées (Mills et al., 2008).

Bien que certains paramètres du patron de marche semblent changer avec le vieillissement, il n’existe, à notre connaissance, aucune données normatives touchant l’ensemble des paramètres spatio-temporels et de dégagement du pied pour les gens âgés de plus de 50 ans. De plus, la plupart des études existantes comparent les jeunes (18 – 59 ans) et les personnes âgées (60 ans et plus) plutôt que de diviser les populations étudiées selon la décennie. Ainsi, il est difficile d’identifier la tranche d’âge clé à partir de laquelle les changements associés au processus de vieillissement modifient ou, du moins, influencent le patron de marche de l’individu. Sachant que plusieurs conditions chroniques comme la SSL avec CN se manifestent à partir de 50 ans, l’évaluation de la marche et l’identification des changements biomécaniques à la marche attribuables à l’âge sont essentiels. Pour répondre à cette question, une étude visant à évaluer et à comparer les paramètres du patron de marche en fonction de l'âge et du sexe chez les adultes de plus de 50 ans à l’aide de capteurs inertiels a été ajoutée à cette thèse (voir l’article 2 au chapitre 3).

5.3 Influence de la SSL avec CN sur le patron de marche

Comme il est difficile à ce jour de bien identifier quand et comment les paramètres du patron de marche sont affectés par le processus de vieillissement, les déviations du patron de marche engendrées par la SSL avec CN demeurent, elles aussi, difficiles à identifier. Très peu d’études se sont intéressées aux paramètres du patron de marche chez les patients ayant un diagnostic de SSL avec CN.

Récemment, les résultats d’une revue systématique indiquaient que les patients ayant un diagnostic de SSL ont une vitesse de marche, une longueur de foulée ainsi qu’une cadence diminuée en comparaison à des personnes âgées saines (Wang et al., 2022). D’autres études comparatives ont montré une diminution de la cadence, de la vitesse de marche, de la longueur de foulée et une augmentation de la durée du pas chez les patients SSL avec CN en comparaison à des personnes âgées saines (Perring et al., 2020).

Le manque de données probantes sur les déviations du patron de marche des patients ayant un diagnostic de SSL avec CN limite la compréhension des défis spécifiques que rencontre les patients au quotidien. Cette lacune rend d'ailleurs la réadaptation de la marche plus complexe puisqu'il est difficile d'identifier les paramètres du patron de marche modifiés qui peuvent impacter la capacité des patients à marcher plus longtemps. La compréhension de ces déviations et de leur impact sur la capacité de marche permettrait donc de concevoir des programmes de réadaptation physique spécifiques à la condition qui soient efficaces.

Pour cette raison, les paramètres spatio-temporels et les paramètres associés au dégagement du pied chez les patients ayant un diagnostic de SSL avec CN feront l'objet de l'étude 2 de cette thèse doctorale. Cette étude sera présentée au chapitre 4.

6. Facteurs physiques et psychologiques présents chez les patients ayant un diagnostic de SSL avec CN

La SSL avec CN n'affecte pas seulement la capacité de marche, elle est généralement accompagnée de plusieurs modifications sur le plan de la santé physique et psychologique. Sur le plan physique et tel que mentionné précédemment dans cette thèse, la SSL est une cause commune d'incapacité et de douleur au dos et/ou aux jambes (Katz et al., 2022). L'incapacité et l'intensité de la douleur sont d'ailleurs deux mesures de résultats cliniques régulièrement utilisées comme variable cible dans les études contrôlées et randomisées visant à tester l'efficacité des options thérapeutiques conservatrices et invasives (Carlo Ammendolia et al., 2022). Bien que ces facteurs physiques soient présents chez les patients, leur association avec la capacité de marche reste à déterminer.

Sur le plan psychologique, les données probantes actuelles montrent que 20 à 40% des patients ayant un diagnostic de SSL présentent des symptômes associés à la dépression (Sinikallio et al., 2006). D'ailleurs, la dépression semble être un facteur prognostique de l'incapacité et de la sévérité des symptômes post-chirurgicaux (McKillop et al., 2014). Chez les patients ayant des douleurs chroniques, l'influence des facteurs psychologiques sur l'expérience douloureuse et sur l'incapacité est bien connue (Linton & Shaw, 2011). Les craintes associés à la douleur peuvent notamment engendrer des comportements d'évitement, qui, à leur tour, vont contribuer à augmenter l'incapacité, l'anxiété et les symptômes dépressifs (Crombez et al., 2012; Linton & Shaw, 2011). Cette boucle vicieuse est présentée dans le modèle de peur-évitement/kinésiophobie à la figure 1.8. Une étude précédente a comparé la kinésiophobie entre les patients ayant un diagnostic de SSL avec CN et les patients ayant un diagnostic de MAP avec claudication vasculaire et les patients ayant un diagnostic de SSL avec CN présentaient davantage de kinésiophobie (Wood et al., 2012). Bien que plusieurs facteurs psychologiques soient présents chez les patients et que certains semblent avoir une influence négative sur la condition, leur association avec la capacité de marche reste à déterminer. Finalement, l'ensemble des facteurs physiques et psychologiques présents chez les patients contribuent au déclin de leur qualité de vie. En effet, les données probantes indiquent que les patients ayant un diagnostic de SSL ont une qualité de vie plus faible que les individus n'ayant pas cette condition et que les individus ayant des douleurs lombaires chroniques (Koji Otani et al., 2013; Saban et al., 2007).

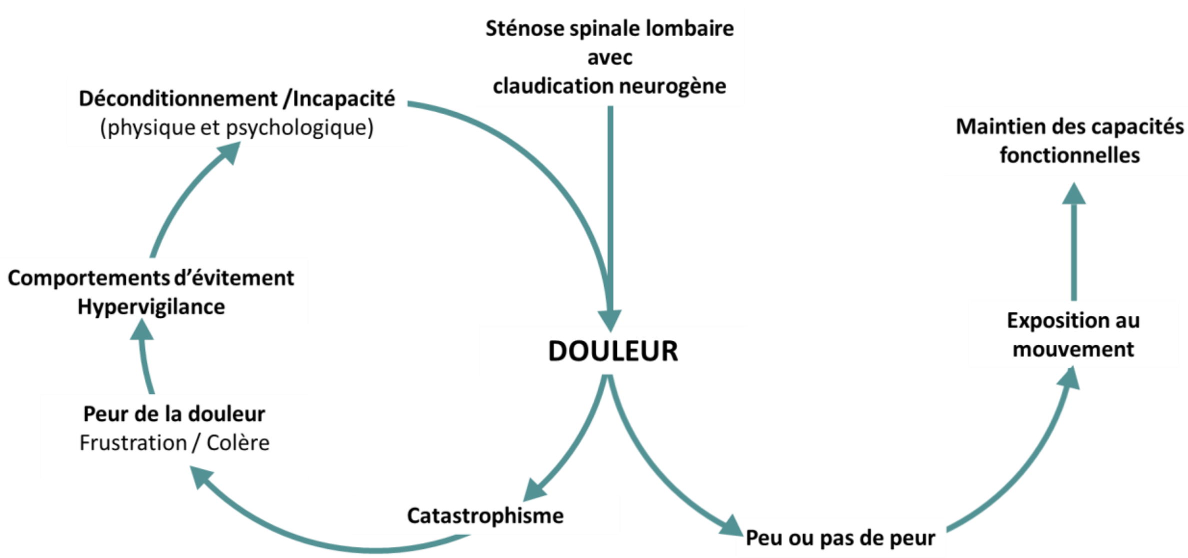

Figure 1.8 - Modèle de kinésiophobie adapté pour la SSL avec CN

(Figure traduite et adaptée de Cook et al., 2006)

Dans un contexte de réadaptation en présence de douleur chronique, l'approche biopsychosocial qui permet d'adresser à la fois les facteurs physiques, psychologiques et sociaux est actuellement considérée comme l'approche la plus efficace (Meeus et al., 2016). L'usage d'exercices dans un environnement où l'alliance thérapeutique entre le professionnel de la santé et le patient est favorable, pourrait contribuer à réduire la peur, l'anxiété et les pensées catastrophiques en plus de contribuer à l'amélioration du sentiment d'auto-efficacité face à la douleur (Moseley et al., 2012). L'éducation, quant à elle, pourrait avoir un effet similaire ou du moins pourrait réduire les pensées négatives en lien avec la condition et l'anxiété (Louw et al., 2011). Ainsi, la combinaison des exercices et de l'éducation pourrait permettre de réduire l'impact des facteurs psychologiques sur la condition en plus de réduire l'incapacité et la douleur. Cette hypothèse sera d'ailleurs mise à l'épreuve dans la quatrième étude de cette thèse. Les options thérapeutiques comme les exercices et l'éducation pour la prise en charge de la SSL seront discutés davantage dans la section 8.

7. Syndrome de fragilité chez les patients ayant un diagnostic de SSL avec CN

En plus des changements physiques et psychologiques associés au vieillissement, la manière dont l'individu vieillit peut également venir teinter les capacités fonctionnelles des patients ayant un diagnostic de SSL avec CN.

Les données probantes actuelles présentent le vieillissement comme un phénomène complexe, naturel qui se veut progressif et irréversible. Celui-ci s'accompagne notamment de plusieurs changements tant au niveau physiologique que psychologique pouvant affecter les capacités fonctionnelles de l'individu. Les récentes données sur le vieillissement abordent une série de facteurs intrinsèques et extrinsèques ayant le potentiel d'influencer directement ou indirectement le vieillissement d'un individu. En effet, l'information relative à la génétique, à l'environnement (p. ex., pollution, situation politique, support social) et au mode de vie de l'individu (p. ex., pratique d'activité physique, saine alimentation) sont des facteurs importants contribuant à la régulation du rythme, à la durée et à la modulation de la qualité du vieillissement. Ainsi, le processus de vieillissement n'est pas le même pour tous. Actuellement, on reconnaît trois différents types de vieillissement : le vieillissement optimal (absence de maladies et d'incapacités, présence d'aptitudes physiques et psychologiques élevées et participation active à la vie sociale), le vieillissement normal (absence de maladies et d'incapacités et présence de facteurs de risque pouvant engendrer une maladie ou des incapacités) et le vieillissement pathologique (présence de maladies ou troubles de santé et présence de plusieurs limitations fonctionnelles).

7.1 Fragilité : Définition et facteurs de risque

En plus du type de vieillissement de l'individu (p. ex., optimal ou pathologique), il est important de noter que la présence d'autres syndromes, comme celui de la fragilité, peuvent être présents chez les individus ayant un diagnostic de SSL avec CN. Bien qu'il n'y ait pas encore de consensus clair sur la définition de ce syndrome (Espinoza & Fried, 2007), la plupart des experts reconnaissent la fragilité comme un syndrome clinique complexe, dynamique et multifactoriel caractérisé par une augmentation de la vulnérabilité de l'individu face à différents facteurs de stress internes ou externes (Clegg et al., 2013; Espinoza & Fried, 2007; Linda P Fried et al., 2001; Hoogendijk et al., 2019; Kojima et al., 2020). Ainsi, un individu dit « fragile » est considéré comme plus vulnérable à la détérioration de son état de santé lorsqu'il se trouve exposé à un stress d'origine psychologique ou physiologique comparativement à un individu sain du même âge (Church et al., 2020). Le syndrome de fragilité présente des manifestations diverses qui s'inscrivent dans un continuum permettant de catégoriser le niveau selon une échelle allant de fragilité légère à sévère (Voyer, 2021). Le syndrome de fragilité implique, entre autres, la diminution de la performance et de la capacité de différents systèmes du corps humain touchant les domaines physique, psychologique, social et cognitif (De Cock et al., 2018). Les principales manifestations cliniques du syndrome de fragilité sont la présence de fatigue, une perte de force musculaire, un ralentissement de la vitesse de marche, un ralentissement moteur, une perte de poids (masse maigre) ainsi qu'une diminution de la fonction cognitive (Espinoza & Fried, 2007; L. P. Fried et al., 2001; Gordon et al., 2020; Voyer, 2021). La fragilité est également associée à un risque de chute plus élevé, à une plus grande incapacité notamment lors de la marche, à une augmentation de l'utilisation des services de santé, à une diminution de la qualité de vie, à une hausse des hospitalisations et de la mortalité (Espinoza & Fried, 2007; L. P. Fried et al., 2001; Hoogendijk et al., 2019; Perracini et al., 2020; Shamliyan et al., 2013).

7.2 Fragilité et SSL avec CN

Il existe à ce jour une forte association entre la fragilité et la présence d'une SSL symptomatique. Cette association pourrait s'expliquer par le fait que la LSS symptomatique engendre des limitations physiques importantes chez les patients (p. ex., réduction de la capacité de marche) et augmente les comportements sédentaires. Ainsi, l'inactivité physique contribue à la perte de masse et de force musculaires ce qui favorise la fragilité physique de l'individu (Kim et al., 2019). La fragilité physique est donc un élément essentiel à prendre en considération lors de l'évaluation des patients et lors de l'élaboration d'options thérapeutiques conservatrices actives pour la prise en charge des patients ayant un diagnostic de SSL avec CN.

8. Lignes directrices pour la prise en charge des patients ayant un diagnostic de SSL avec CN

La diminution de la capacité de marche engendrée par la CN associée à la SSL représente la raison la plus courante pour laquelle les patients recherchent des soins (Fritz et al., 1998; Iversen & Katz, 2001). Cette diminution de la capacité de marche s'accompagne généralement d'un déclin important de la fonction, de la qualité de vie et de l'indépendance des patients ayant un diagnostic de SSL avec CN (Comer et al., 2009). Elle est également associée à une augmentation des niveaux de dépression, d'anxiété et du sentiment de désespoir chez les patients (Carlo Ammendolia et al., 2017; Sinikallio et al., 2006). En ce sens, la prise en charge des patients devrait considérer les aspects physiques et psychologiques pouvant être affectés qui découle de la SSL avec CN afin de permettre aux patients de maintenir leurs capacités physiques actuelles voire de les améliorer.

Les plus récentes lignes directrices cliniques en matière de prise en charge des patients ayant un diagnostic de SSL avec CN de même que les plus récents consensus d'experts stipulent que les interventions thérapeutiques conservatrices comme l'éducation, les exercices et les thérapies manuelles devraient être offertes comme soins de première intention (Bussières et al., 2021; Comer et al., 2022; Fornari et al., 2020; M. Kawakami et al., 2023). Plusieurs mentionnent même que les soins conservateurs devraient être pleinement exploités avant d'envisager des interventions plus invasives comme les injections ou la chirurgie (Bussières et al., 2021; Comer et al., 2022; Rousing et al., 2019). En 2022, un consensus d'experts a développé un algorithme de prise en charge pour la SSL avec CN afin de fournir un outil pour la trajectoire de soins des patients ayant une SSL avec CN aux professionnels de la santé (voir figure 1.9).

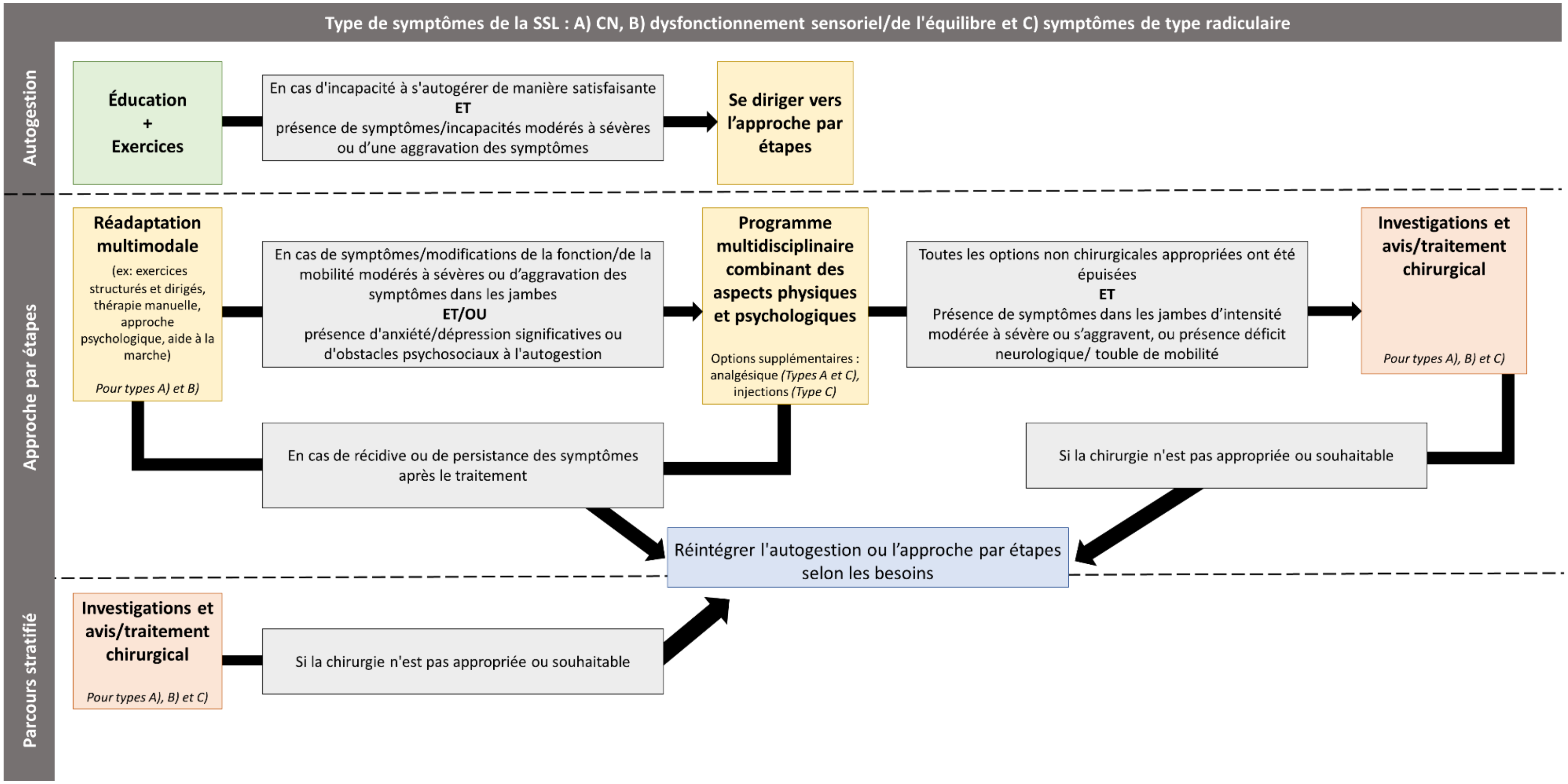

Figure 1.9 - Algorithme de prise en charge pour la SSL avec CN en fonction des symptômes

(Figure traduite et adaptée de Comer et al., 2022)

Bien que la chirurgie soit l'intervention envisagée pour certains sous-groupes de patients ayant un diagnostic de SSL avec CN, les soins conservateurs comme les exercices et l'éducation peuvent jouer un rôle crucial avant l'intervention chirurgicale pour limiter le déclin fonctionnel. De plus, tous les individus ne nécessitent pas ou ne sont tout simplement pas éligibles à la chirurgie notamment en raison des risques associés aux autres comorbidités que peuvent présenter les patients. Généralement, la chirurgie est envisagée lorsqu'il y a échec des soins conservateurs, une détérioration de la condition, c'est-à-dire des symptômes plus importants ainsi que plus d'incapacité, ou une apparition de drapeaux rouges (p. ex., pertes de sensation, incontinence). Finalement, il est courant que les patients reçoivent une intervention pharmacologique en parallèle aux autres modalités de traitement conservateurs comme les exercices (Diwan et al., 2019). Les prochaines sections permettront de mettre en évidence les modalités de soins pouvant être offertes aux patients.

8.1 Approche multimodale

L'approche multimodale inclue généralement combinaison d'interventions conservatrices comme les exercices (supervisés ou non), l'éducation au patient et les consultations en physiothérapie ou en chiropratique (C. Ammendolia et al., 2022; Fornari et al., 2020; Minetama et al., 2019; Schneider et al., 2019). C'est actuellement l'approche conservatrice la plus recommandée et priorisée par les lignes directrices cliniques canadiennes en matière de prise en charge de la SSL avec CN (Bussières et al., 2021). Une récente revue de la littérature rapporte qu'il y a des évidences modérées qui indiquent qu'un programme structuré multimodal de 6 semaines combinant la thérapie manuelle et des exercices, avec ou sans éducation, est efficace pour la CN (C. Ammendolia et al., 2022). Cependant, plusieurs études soulèvent le manque de données probantes de qualité concernant l'efficacité des différents types d'interventions conservatrices à court et long terme sur la capacité de marche, la douleur et l'incapacité liée à la SSL (C. Ammendolia et al., 2022; Minetama et al., 2019; Thornes et al., 2020). Malgré le manque de données probantes, l'approche multimodale centrée sur le patient est généralement favorisée (Kirker et al., 2023) puisque celle-ci engendre des bénéfices sur la santé globale (M. Kawakami et al., 2023) et qu'elle présente très peu d'effets secondaires néfastes pour le patient (Fornari et al., 2020). L'approche multimodale inclue des modalités passives comme la thérapie manuelle et actives comme les exercices. Les thérapies passives nécessitent des rendez-vous auprès d'un professionnel de la santé qui engendrent des coûts et des déplacements pour le patient. À l'inverse, les exercices peuvent être réalisés dans le confort du domicile, avec ou sans supervision.

8.1.1 Éducation

Dans les dernières années, quelques auteurs ont inclus des éléments d'éducation au patient dans leurs essais contrôlés et randomisés (Ammendolia et al., 2018; Schneider et al., 2019; Williamson et al., 2022) sans toutefois décrire la nature exacte de l'information présentée (p. ex., recommandations sur la pratique d'activité physique, explications en lien avec la condition) ni la façon de la rendre disponible aux patients (p. ex., rencontres, dépliant d'information). Seule l'étude de Comer et al. (2013) précise que l'éducation au patient comprenait les éléments suivants : informations sur la CN et la SSL, les symptômes, les causes possibles, le processus diagnostique, les modalités de traitement envisageables, et des conseils pour mieux vivre avec la SSL (Comer et al., 2013). L'éducation a le potentiel d'aider les individus à mieux comprendre leur condition, l'évolution naturelle de la SSL avant CN, les options de traitement (p. ex., les exercices) et sur la suite logique des modalités de traitement offertes (p. ex., essayer les interventions conservatrices avant de recourir à des injections ou à la chirurgie). Ce besoin d'être mieux informés a d'ailleurs été rapporté par les patients dans le cadre d'études qualitatives (A. M. Bove et al., 2018; Lyle et al., 2017). À ce jour, il n'existe pas de programme d'éducation spécifiquement dédié aux patients ayant un diagnostic de SSL avec CN (Comer et al., 2022). À notre connaissance, il n'existe aucune donnée probante sur l'efficacité de l'éducation seule comme intervention conservatrice.

8.1.2 Exercices

Concernant les exercices, il n'existe, à ce jour, aucune recommandation claire concernant le type d'exercices à inclure dans un programme de réadaptation pour la SSL avec CN ni sur les modalités relatives à la prescription de ces exercices (p. ex., temps, tempo, nombre de séries). Une revue systématique indique que les exercices de groupe en milieu communautaire améliorent la pratique d'activité physique à court terme en comparaison aux soins médicaux (C. Ammendolia et al., 2022). Plusieurs études incluses dans cette revue systématique incluaient des modalités de traitement combinant la thérapie manuelle et les exercices. L'efficacité des exercices seuls n'a toutefois pas été investiguée par les auteurs. Les résultats issus d'une autre revue systématique parue en 2022 indiquent que les exercices supervisés ont une meilleure efficacité que les exercices réalisés à la maison et que l'autogestion pour la prise en charge de la SSL (Özden et al., 2022). Cette même revue suggère aussi l'utilisation d'exercices de stabilisation du tronc, d'exercices aquatiques et d'exercices aérobiques (p. ex., tapis roulant ou vélo). Le choix des exercices inclus dans un programme de réadaptation spécifique devrait être basé sur les paramètres visés par le programme de réadaptation (p. ex., réduction de la douleur, incapacité) (Özden et al., 2022). Une récente revue systématique de Comer et ses collègues rapporte que les programmes de réadaptation incluant des exercices sont généralement réalisés sous la supervision d'un professionnel de la santé sur une durée d'environ six semaines à raison de deux fois par semaine et que la durée des sessions d'exercices varie entre 30 et 60 minutes. Cette même revue systématique mentionne que les exercices sont généralement axés sur le renforcement musculaire, la capacité aérobie (p. ex., vélo) et les étirements (Comer et al., 2024). Ces résultats sont cohérents avec les données probantes actuelles sur les conditions musculosquelettiques chroniques. En effet, un minimum de 2 séances d'exercices par semaine est généralement recommandé pour observer une amélioration significative de la capacité fonctionnelle (Young et al., 2018)

8.1.3 Thérapie manuelle

La thérapie manuelle semble être efficace pour les patients lorsqu'elle est offerte en complément à un programme d'exercices (Özden et al., 2022). L'efficacité de la manipulation vertébrale seule semble toutefois être équivalente à l'efficacité d'une liste d'attente à très court terme pour l'ensemble des mesures de résultats cliniques (p. ex., douleur et incapacité) (C. Ammendolia et al., 2022).

La thérapie manuelle comprend généralement des mobilisations par distraction lombaire, des mobilisations de l'articulation de la hanche, des mobilisations au niveau des articulations lombaires et sacro-iliaques en position latérale, et parfois, des techniques neurodynamiques (C. Ammendolia et al., 2022; Schneider et al., 2019).

8.2 Autres modalités de traitement

Comme mentionné précédemment, il existe d'autres modalités de traitement que l'éducation, les exercices et la thérapie manuelle pouvant être utilisées dans la prise en charge des patients ayant un diagnostic de SSL avec CN. Bien que ces modalités de traitement ne fassent pas partie intégrante de la thèse, celles-ci seront brièvement nommées et présentées puisque certains patients inclus dans les différents projets de cette thèse pourraient y avoir eu recours ou planifient y avoir recours. Ces modalités de traitement comprennent le recours à l'acupuncture, aux traitements pharmacologiques, aux injections ainsi qu'à la chirurgie.

8.2.1 Acupuncture

L'efficacité de l'acupuncture seule comme modalité de traitement pour la SSL avec CN ne semble, à notre connaissance, pas avoir été étudiée. Cependant, une récente revue systématique soulève que la combinaison de l'acupuncture et des soins usuels n'avait pas une efficacité à court terme supérieure à l'usage des soins usuels seuls pour l'ensemble des mesures de résultats cliniques (p. ex., douleur) (C. Ammendolia et al., 2022).

8.2.2 Les traitements pharmacologiques

Malgré le fait que les données probantes concernant l'efficacité de la médication sur l'amélioration de la capacité de marche et de la réduction des symptômes, tels que la douleur au dos et aux jambes, soient généralement de très faible qualité (C. Ammendolia et al., 2022), la plupart des patients ayant un diagnostic de SSL avec CN ont tout de même recours à la médication comme soins de première intention (Fritz et al., 1998). Les familles de médicaments que l'on retrouvent généralement dans les prescriptions des patients sont les anti-inflammatoires non-stéroïdiens (AINS), les analgésiques (p. ex., méthylcobalamine, paracétamol et calcitonine), les antidépresseurs tricycliques, les inhibiteurs de la recapture de la sérotonine et de la noradrénaline, les opioïdes, les relaxants musculaires, le prégabalin et le gabapentin (Katz et al., 2022). Le consensus d'experts présenté dans les dernières lignes directrices cliniques canadiennes indique que les AINS tout comme les analgésiques, les opioïdes, les relaxants musculaires le prégabalin et le gabapentin ne devraient pas être recommandés dans un contexte de première ligne pour les patients ayant un diagnostic de SSL avec CN (Bussières et al., 2021). Les lignes directrices danoises publiées quelques années plus tôt ne recommandaient pas non plus l'utilisation d'AINS, de paracétamol et de relaxants musculaires notamment en raison du manque d'évidences scientifiques et les risques d'effets secondaires indésirables (Rousing et al., 2019). En ce qui concerne les antidépresseurs tricycliques et les inhibiteurs de la recapture de la sérotonine et de la noradrénaline, les lignes directrices canadiennes recommandent leur utilisation pour les patients ayant une SSL avec une CN et qui présentent des douleurs lombaires (Bussières et al., 2021). Bien que l'efficacité des traitements pharmacologiques ne soit pas abordée dans cette thèse, les participants inclus dans les différents projets de la thèse avaient généralement une prescription médicale active pour l'un ou plusieurs des médicaments présentés.

8.2.3 Les injections

À ce jour, les injections épidurales ne sont pas recommandées pour la prise en charge de la SSL. En effet, les dernières lignes directrices de même que les plus récentes revues systématiques portant sur l'efficacité des modalités de traitement conservateurs dans la prise en charge des patients n'encouragent pas leur utilisation en raison de la nature plutôt faible des données probantes existantes à leur égard (C. Ammendolia et al., 2022; Ammendolia et al., 2012; Bussières et al., 2021). De plus, les injections de glucocorticoïde-lidocaïne ou de lidocaïne seule peuvent engendrer des effets secondaires néfastes comme des maux de tête, de la fièvre, des infections, des troubles cardiaques ou pulmonaires, des vertiges ou des gonflements au niveau des jambes (C. Ammendolia et al., 2022).

8.2.4 La chirurgie

La chirurgie est l'option thérapeutique ultime envisagée chez les patients ayant un diagnostic de SSL avec CN. Pour avoir recours à la chirurgie, les modalités de traitement conservateurs doivent avoir échoué, et les symptômes incapacitants doivent persister. Malgré l'évolution naturelle de la SSL plutôt favorable puisque près de 60% des patients verront une amélioration ou une stabilisation de leurs symptômes (Minamide et al., 2013; Wessberg & Frennered, 2017), la SSL demeure la raison la plus commune de chirurgie de la colonne vertébrale chez les patients âgés de plus de 65 ans (Deyo et al., 2010).

Pour la prise en charge de la SSL, le type d'intervention chirurgicale utilisé dépend du type de SSL présent chez le patient (p. ex., sténose centrale dégénérative ou sténose foraminale) et de la symptomatologie (dominance de la douleur au dos ou au niveau des jambes). Les principales techniques chirurgicales utilisées incluent des approches ouvertes comme la laminectomie, des approches minimalement invasives comme la laminotomie unilatérale ou bilatérale ainsi que des approches faisant intervenir des techniques de fusion des vertèbres (Jansson et al., 2003; Spetzger et al., 1997; Zhang et al., 2021). L'efficacité de la chirurgie à court terme est généralement supérieure à l'efficacité des modalités de traitement conservateurs comme les exercices et l'éducation (Katz et al., 2022; Kovacs et al., 2011; May & Comer, 2013). En effet, la chirurgie peut rapidement réduire la douleur et l'incapacité (Ma et al., 2017). Cependant, les bénéfices cliniques s'estompent généralement avec le temps (Ilyas et al., 2019; Lurie et al., 2015). De plus, la chirurgie présente généralement plus d'effets secondaires néfastes que les modalités de traitement conservateurs et les patients optant pour ce traitement présentent un risque de réopération de 18% sur une période de 8 ans (Lurie et al., 2015).

8.3 Besoins thérapeutiques pour la SSL avec CN

À l'heure actuelle, et malgré les dernières recommandations concernant la prise en charge, aucune ressource spécifiquement dédiée aux patients ayant un diagnostic de SSL avec CN n'est disponible. Pourtant, la progression plutôt lente de la SSL offre une fenêtre de temps intéressante pour l'utilisation des interventions conservatrices sécuritaires comme les exercices (Marchand et al., 2021).

Le développement de soins conservateurs adaptés est donc crucial pour améliorer la prise en charge des patients ayant un diagnostic de SSL avec CN. De plus, l'utilisation de soins conservateurs comme les exercices permettent aux patients d'être directement impliqués dans leur propre réadaptation tout en contribuant à l'amélioration de leur qualité de vie. De récentes études ont d'ailleurs rapportées que les patients avaient le besoin d'être plus informés sur leur condition de santé ainsi que sur leur trajectoire de soins (Comer et al., 2022; Lyle et al., 2017). Il est donc possible d'émettre l'hypothèse qu'en ayant de meilleures connaissances sur leur condition et en les impliquant directement dans le processus décisionnel quant à leur trajectoire de soins, les patients se sentiraient mieux outiller pour gérer eux-mêmes leurs symptômes au quotidien. De plus, une meilleure connaissance de leur condition leur permettrait aussi d'adhérer davantage aux options thérapeutiques envisagées. La combinaison des exercices et de l'éducation est donc intéressante puisqu'elle implique des modalités actives qui peuvent être mise en place autant dans un environnement clinique qu'à la maison.

Ainsi, l'étude randomisée et contrôlée présentée dans le chapitre 6 de cette thèse s'inscrit dans une perspective de prise en charge clinique conservatrice qui favorisera l'utilisation d'exercices spécifiques et l'éducation des patients dans le but d'améliorer la capacité de marche de ces derniers.

9. Problématique et objectifs de la thèse

Le déclin de la capacité à marcher au quotidien est la principale préoccupation pour les patients ayant un diagnostic de SSL avec CN. Il est crucial de s'intéresser aux facteurs physiques et psychologiques présents chez les patients qui pourraient influencer le déclin de cette capacité de marche. Actuellement, on sait que ces patients présentent divers facteurs physiques (p. ex., douleurs aux jambes et au dos, incapacité) et psychologiques (p. ex., anxiété) qui contribuent à la diminution de leur qualité de vie. Toutefois, il existe, à notre connaissance, peu d'information sur l'association entre, d'une part, les facteurs physiques et psychologiques et, d'autre part, la capacité de marche des patients ayant un diagnostic de SSL avec CN. Une meilleure connaissance de ces associations pourrait permettre de développer des interventions conservatrices comme des exercices et des séances d'éducation adaptés pour améliorer la capacité de marche des patients.

Également, bien que le patron de marche des patients ayant un diagnostic de SSL avec CN soit modifié, il existe peu d'information sur les différences observées quant aux caractéristiques du patron de marche entre les personnes âgées qui présentent une SSL avec CN et les personnes âgées qui n'ont pas de douleur. Établir les différences entre ces groupes d'individus demeure essentiel afin d'identifier les paramètres de la marche qui se trouvent modifiés en raison de la condition plutôt que par le processus de vieillissement normal de l'individu.

En plus d'être préoccupés par leur capacité de marche, les patients expriment le besoin d'avoir accès à des ressources afin de mieux comprendre leur condition et d'établir des plans d'action clairs leur permettant d'améliorer leur capacité à marcher plus longtemps ou plus loin avant de devoir s'arrêter. Actuellement, les guides de bonnes pratiques et les consensus d'experts recommandent l'utilisation d'approches conservatrices, telles que les exercices et l'éducation, comme soins de première intention pour la prise en charge des patients atteints de SSL avec CN. Bien que les exercices et l'éducation soient des interventions sécuritaires pour les patients ayant un SSL avec CN, il existe à ce jour très peu d'information sur l'efficacité à la fois de la combinaison des exercices et de l'éducation et sur l'éducation seule comme soins de première intention pour améliorer la capacité de marche des patients. De plus, les informations sont très limitées concernant le contenu de tels programmes d'exercices et d'éducation de même que sur les modalités offertes aux patients pour chacune de ces approches conservatrices.

Ainsi, les objectifs spécifiques de la thèse étaient donc :

1) D'identifier les facteurs physiques et psychologiques associés au déclin des capacités fonctionnelles des patients ayant une SSL, en s'intéressant plus particulièrement à la marche.
2) De comparer les paramètres de la marche de personnes âgées sans douleur en fonction de l'âge et du sexe avec des capteurs inertiels afin d'établir des mesures de références.
3) De comparer les paramètres de la marche des patients ayant une SSL à ceux de personnes âgées sans douleur à l'aide de capteurs inertiels.
4) D'évaluer l'efficacité d'un programme de réadaptation combinant des exercices et de l'éducation comparativement à l'éducation seule sur l'amélioration de la capacité de marche des patients ayant une SSL.

Chapitre 2 – Article 1, Physical and psychological factors associated with walking capacity in patients with lumbar spinal stenosis with neurogenic claudication: a systematic scoping review

Ce chapitre inclut le premier article de cette thèse qui a été publié dans la revue « *Frontiers in Neurology* » en 2021.

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Key Words: *lumbar spinal stenosis, neurogenic claudication, walking capacity, gait pattern characteristics, functional task*

Résumé

Objectif : Cette étude visait à évaluer l'état actuel des connaissances scientifiques sur les facteurs physiques et psychologiques associés à la capacité de marche chez les patients atteints de sténose spinale lombaire (SSL) avec claudication neurogène (CN).

Devis de recherche : Revue systématique de portée

Recherche bibliographique : Les bases de données CINAHL (Cumulative Index to Nursing and Allied Health Literature), MEDLINE, Cochrane, PsycINFO et SPORTDiscus ont été consultés.

Critères de sélection des études : Les études de cohortes et les études transversales rapportant des associations entre d'une part les facteurs physiques ou psychologiques et d'autre part la capacité de marche chez les patients présentant une SSL symptomatique ont été incluses.

Synthèse des données : Les données ont été synthétisées afin d'identifier les associations entre les facteurs physiques ou psychologiques et la capacité de marche, les caractéristiques du patron de marche, ou la performance lors de tâches fonctionnelles.

Résultats : Vingt-quatre études ont été incluses. La capacité de marche était significativement corrélée avec plusieurs résultats liés à la douleur, à l'incapacité, à la distance de marche estimée et à la surface transversale de la colonne lombaire. Les caractéristiques du schéma de marche, telles que la vitesse et la longueur des enjambées, étaient fortement et positivement corrélées avec les résultats liés à l'incapacité. La performance dans les tâches fonctionnelles étaient significativement corrélées avec l'incapacité lombaire et des membres supérieurs, l'endurance musculaire des membres inférieurs, les amplitudes de mouvement et la vitesse. Les associations avec les facteurs psychologiques étaient principalement contradictoires, à l'exception du Rasch-based Depression Screener et du questionnaire Pain Anxiety Symptom Scale (PASS-20), qui étaient associés à une diminution de la performance dans les tâches fonctionnelles.

Conclusion : Les facteurs physiques et psychologiques associés à la capacité de marche chez les patients atteints de SSL symptomatique ont été identifiés. Cependant, de nombreuses associations entre ces facteurs et la capacité de marche étaient contradictoires, en particulier lorsqu'elles étaient corrélées spécifiquement avec la capacité de marche.

Mots-clés : *sténose lombaire, claudication neurogène, capacité de marche, caractéristiques du schéma de marche, tâche fonctionnelle*

Abstract

Objective: The purpose of this study was to evaluate the current state of scientific knowledge regarding physical and psychological factors associated with walking capacity in patients with lumbar spinal stenosis (LSS) with neurogenic claudication.

Design: Systematic scoping review

Literature Search: We searched CINAHL (Cumulative Index to Nursing and Allied Health Literature), MEDLINE, Cochrane, PsycINFO and SPORTDiscus databases.

Study Selection Criteria: Cohorts and cross-sectional studies reporting on associations between physical or psychological factors and impaired walking capacity in patients with symptomatic LSS were included.

Data Synthesis: Data were synthetized to identify associations between physical or psychological factors and either walking capacity, gait pattern characteristics or functional tasks.

Results: Twenty-four studies were included. Walking capacity was significantly correlated with several pain outcomes, disability, estimated walking distance and cross-sectional area of the lumbar spine. Gait pattern characteristics such as speed and stride were strongly and positively correlated with disability outcomes. Functional tasks were significantly correlated with lower back and upper limb disability, lower limb endurance strength, ranges of motion and speed. Associations with psychological factors were mostly conflicting except for the Rasch-based Depression Screener and the Pain Anxiety Symptom Scale (PASS-20) questionnaire that were associated with a decreased performance in functional tasks.

Conclusion: Physical and psychological factors that are associated with walking capacity in patients with symptomatic LSS were identified. However, many associations reported between physical or psychological factors and walking capacity were conflicting, even more so when correlated with walking capacity specifically.

Key Words: *lumbar spinal stenosis, neurogenic claudication, walking capacity, gait pattern characteristics, functional task*

INTRODUCTION

Symptomatic lumbar spinal stenosis (LSS), characterized by a limited walking capacity due to leg pain, is a leading cause of disability in the elderly (Ammendolia et al., 2018; Budithi et al., 2017). Narrowing of the lumbar spinal canal or lateral foramina, as well as compression or decreased blood flow to the nerve roots (Hartvigsen et al., 2018; Kobayashi, 2014) are considered the main causes of pain in this musculoskeletal condition. Lumbar spinal stenosis is affecting between 11% and 39% (Jensen et al., 2020; Kalichman et al., 2009) of the global population, especially people over the age of 65 (Comer et al., 2009; Jensen et al., 2020). The acquired form of LSS arises from degenerative changes, including disc degeneration (herniation or bulging), hypertrophy of the ligamentum flavum, and spondylolisthesis and/or facet osteoarthritis (S. Genevay & S. J. Atlas, 2010; Hartvigsen et al., 2018; Kobayashi, 2014) and can involve the central canal, lateral recess, foramina or any combination of these anatomical sites (Stephane Genevay & Steven J Atlas, 2010). Congenital LSS is due to abnormalities during development, leading up to smaller pedicles length, which directly affects the antero-posterior diameter of the spinal canal (Singh et al., 2005).

In patients with LSS, self-reported symptoms combined with a physical examination represent the main assessment components of the clinical portrait severity, considering that symptoms and associated disability do not always correlate with results from magnetic resonance imaging (MRI). Advanced imaging provides information on the presence and extent of lumbar spine degenerative changes and on the lumbar spinal canal size, but does not translate information on functional capacity (Jensen et al., 2020). Indeed, a number of patients will show clear and severe signs of stenosis on imaging but will experience few or no symptoms. Commonly reported symptoms of LSS include leg pain, numbness, cramps, fatigue and weakness (Stephane Genevay & Steven J Atlas, 2010; Lurie & Tomkins-Lane, 2016). These symptoms can be grouped under one appellation: neurogenic claudication (NC). The presence of NC is modulated by the patient's posture, as it is brought on by lumbar extension when standing or walking and relieved by lumbar flexion (i.e. sitting or bending forward) (Stephane Genevay & Steven J Atlas, 2010).

Neurogenic claudication is triggered by performing daily activities that require prolonged standing postures such as walking, and patients often face a decrease in quality of life (QoL) due to important walking and functional limitations. The assessment of walking limitations plays a central role in LSS management, both in the decision-making process regarding the diagnosis (Tomkins-Lane et al., 2020) and treatment options (Tomkins-Lane et al., 2012). Most recent studies evaluating treatment effects in patients with LSS have measured walking abilities using different assessment methods. Some of these studies focused on walking distance (Barz et al., 2008; Tomkins-Lane & Battie, 2013; Williamson et al., 2018), while others focused on walking time (Ammendolia et al., 2016; Marchand et al., 2019), or both (Rainville et al., 2012; Zeifang et al., 2008) to report on walking capacity. Indeed, severe symptoms combined with a decrease in walking capacity, and subsequently in QoL, prompt neurosurgeons to opt for surgery in patients with LSS (Quack et al., 2019; Takenaka et al., 2019).

Walking impairment is a major issue in LSS, and many physical and psychological factors are related to this decrease in functional capacity. Several gait measures such as step length, cadence, step width, and gait cycle have been assessed in LSS patients, but it is not clear if and how they relate to the decline in walking capacity. It is also known that walking limitations can negatively influence or be influenced by psychological factors such as a perceived low QoL and self-efficacy, and increased anxiety and kinesiophobia (Ammendolia et al., 2017; Mullen et al., 2012). Assessing physical and psychological factors may provide relevant information that would improve our understanding of how LSS affects daily activities.

The purpose of this study was to evaluate the current state of scientific knowledge regarding physical and psychological factors associated with walking capacity in patients with LSS and associated NC.

METHODS

As systematic scoping reviews are used to inform future research directions, this study design was deemed the most appropriate to capture information from heterogeneous studies, map existing literature and identify knowledge gaps (Peters et al., 2015). This scoping review was based on the framework of Levac et al. using a 5-step review method (Levac et al., 2010) and on the framework of Peters et al. for the systematic aspect of the study conduct (Peters et al., 2015). This study was registered on Open Science Framework (DOI 10.17605/OSF.IO/6AZ7C).

Step 1: Identifying the research question

This scoping review was conducted to answer the following question: What are the physical and psychological factors associated with walking capacity in patients with LSS and associated NC?

The main focus of this systematic scoping review was walking capacity in patients with LSS and associated NC. Exploring associations between physical or psychological factors and walking capacity or performance in functional tasks should provide critical information regarding the impact of LSS on daily functioning. Interventions targeting physical and psychological factors associated with the decline in walking capacity could improve patients' walking capacity and QoL and support surgical decision-making.

Step 2: Identifying relevant studies

The search strategy was elaborated in collaboration with a university librarian and was conducted using CINAHL (Cumulative Index to Nursing and Allied Health Literature), MEDLINE, Cochrane, PsycINFO and SPORTDiscus databases from inception to October 4, 2019. Then, an update of the literature was completed on June 18, 2020. A combination of keywords and MeSH terms was used to identify relevant studies. The lead investigator (MH) conducted the literature search. The search strategy was first developed for MEDLINE and adapted to other databases when needed (see Supplement 1). Other sources such as Google Scholar and reference lists of relevant studies were hand-searched to ensure a comprehensive overview of the subject. An EndNote library (version X9, Clarivate Analytics, Boston, MA, USA) was created to import all citations from the search strategy. Then, all duplicates were identified and removed.

Step 3: Study selection

Definitions of key concepts

Symptomatic LSS was defined as back and/or leg pain causing NC in patients diagnosed with degenerative LSS. The targeted outcome was walking capacity which was considered from two different perspectives: walking capacity defined as a distance or time spent walking, and walking capacity defined as performance during a functional task that repetitively involve lower limbs and/or trunk movement (e.g. the Timed Up and Go test or stairs climbing). Associated factors of walking capacity were regarded as either physical or psychological. Physical factors were divided into patient-reported outcome measures (PROMs) (e.g. pain, disability and QoL) and objectives measures (e.g. gait pattern characteristics (e.g. speed, cadence, and step width), lower limb strength and range or motion (ROM)) while psychological factors of interest included anxiety, depression, kinesiophobia, frailty and self-efficacy.

Inclusion and exclusion criteria

To be included in this scoping review, studies had to be limited to human participants and be published in peer-reviewed scientific journals in either French, English or Spanish language. Study designs were limited to cohort, and cross-sectional studies. Randomized controlled trials were also considered provided that they present baseline data of participants with LSS and associated NC and reported on correlation or regression prior to the beginning of the intervention. In addition, assessments had to include at least one physical and/or psychological outcome measures. To be include, studies needed to fulfill inclusion criteria regarding the specific populations (P), intervention (I) and outcomes measures (O) that are presented in table 2.1. In addition, studies that included participants with congenital LSS, scoliosis, or vascular claudication were excluded. The following types of publication were also excluded: validation study, case study, cases series, systematic review and meta-analysis, grey literature, and governmental documents.

Table 2.1 - inclusion criteria regarding population, intervention, and outcomes measures

	P	I	C	O
Inclusion criteria	• Patients with LSS: Localization: - Central - Foraminal - Lateral - With or without spondylolisthesis - Coexisting LSS types (e.g., central + foraminal) • Presenting with NC • Having at least 18 years old	• Associations provided before any medical intervention is initiated • Data collected during one of these situations: - Walking - Climbing stairs - Running - Functional tasks	• Non applicable	• Physical and psychological factors related to: - Walking capacity - Functional tasks - Gait pattern characteristics
Note	*If there was a mixed sample size (e.g. LSS and healthy participants), the study was kept only if data from patients with LSS could be extracted separately.*			

P= Population, I= Intervention, C= Comparison, O=Outcome measures, LSS = lumbar spinal stenosis, NC = neurogenic claudication

Screening

All potentially eligible articles were independently screened by a pair of reviewers (MH, MERP) in two phases, using a standardized Excel spreadsheet. In phase one screening, titles and abstracts were classified as relevant, possibly relevant or irrelevant according to the eligibility criteria. Then during phase two screening, the full text of possibly relevant articles was reviewed by the same pair of reviewers for final determination of eligibility. Reviewers discussed disagreement to reach consensus for both phases of screening and a third independent reviewer (AAM) was consulted to achieve consensus if needed.

Step 4: Charting the data

The following descriptive variables were extracted from all relevant studies using a standardized extraction form: authors, year of publication, title, country, study design, sample size, definitions of both LSS and NC, description of the study population (number of participants with LSS, LSS type, age, and gender ratio), independent variables, dependent variables, and key findings from study results. A pair of researchers independently extracted data (MH, JDB) and if necessary, a third person (AAM) was involved to resolve disagreements.

Step 5: Collating, summarizing and reporting results

Study designs and participants

Data regarding study designs, sample sizes, and patients' characteristics were summarized to provide an overall picture of the populations studied.

Quality assessment

Quality assessment of all eligible studies was independently completed by two reviewers (MH, JDB) using the Appraisal tool for Cross-Sectional Studies (AXIS)(Downes et al., 2016). When a disagreement between the two reviewers occurred, a third person (AAM) was involved to reach consensus. The AXIS tool contains 20 questions that address three different domains: study design (7 questions), study quality (7 questions) and risk of bias (6 questions). Each question is answered by either "yes" (1 point), "no" (0 point) or "do not know" (0 point). A sum of all "yeses" is calculated to provide an overall score with higher scores indicating higher quality. As none of the studies reported a description of the non-responders (question 7), question 14 ("If appropriate, was information about non-responders described?") became non-applicable and therefore was removed from the quality assessment checklist, bringing the maximum possible score to 19. Furthermore, question 19 ("Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the result?") was given one point when it was specified that there were no conflicts of interest.

Results organization

Results were first organized into two broad categories based on the nature of the reported associations. The categories were defined as follow: associations in relation to [1] walking capacity, and [2] functional tasks. Then, within each category, results were organized based on outcome measure types (i.e. PROMs, objective outcome measures, and any other relevant outcome whenever applicable).

RESULTS

The initial literature search identified 6,034 possible studies for inclusion in the scoping review. Following the removal of duplicates (n=1,665), 4,369 studies remained. Initial screening of titles and abstracts resulted in the exclusion of 4316 articles that did not meet inclusion criteria. Out of the remaining 54 full-text articles, 21 fulfilled the inclusion criteria. Frequent updates of the search strategy were conducted during the review process. In light of the last update conducted on July 15, 2021, three additional articles fulfilling inclusion criteria were found bringing the final number of included studies to 24. All studies were published between 2011 and 2020 from 11 different countries over 3 continents (see Supplement Material 2 for more details - *Annexe A de la thèse*). Figure 2.1 presents the study selection flowchart.

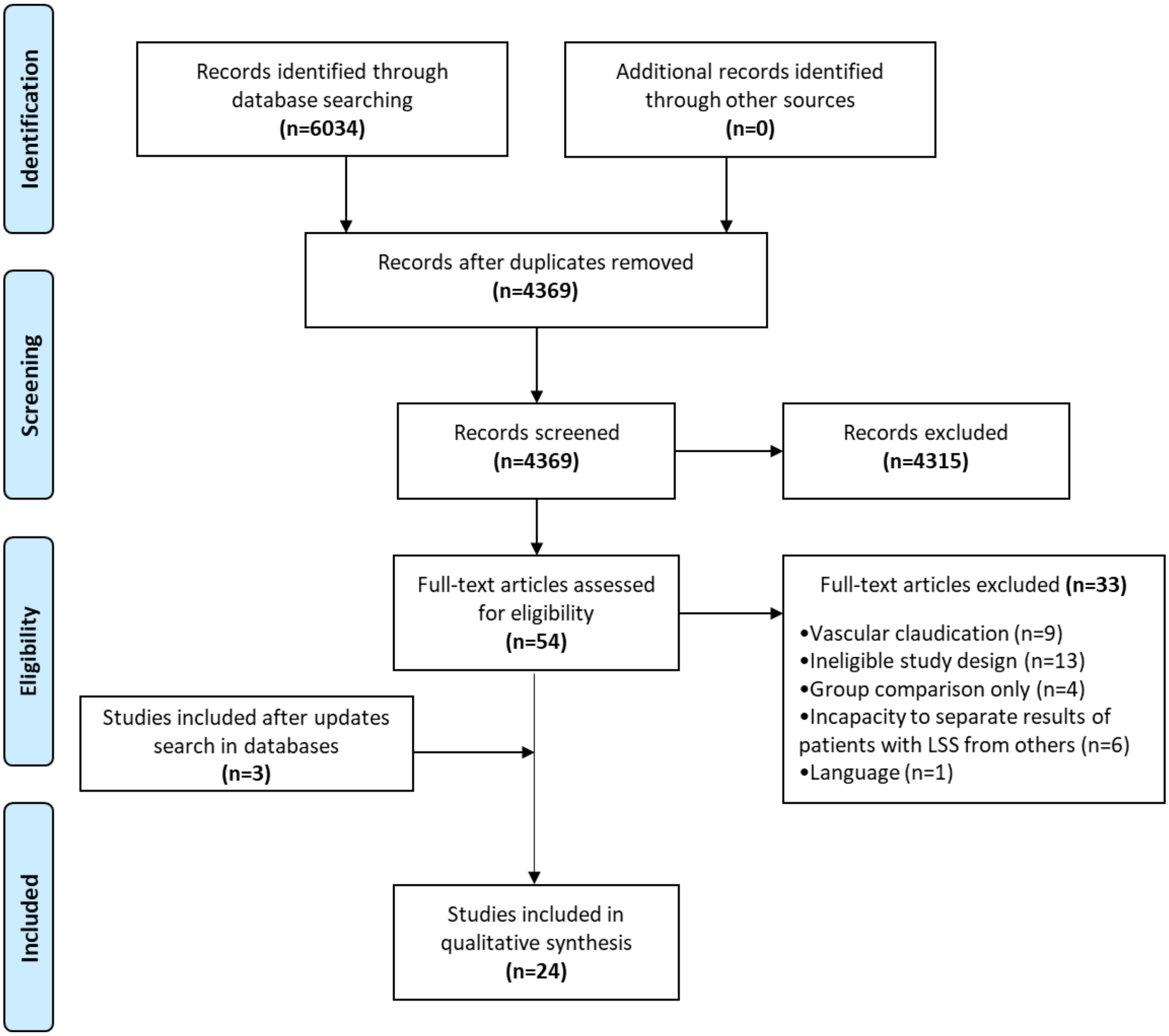

Figure 2.1 – PRISMA flowchart

Participants

Out of the 24 studies, seventeen were cross-sectional studies, five were prospective observational studies, one was a secondary analysis of a RCT, and one was a retrospective observational study. Sample sizes ranged from 12 to 1009 participants. In addition, out of the 2,973 participants included in the 24 studies, 1,694 had symptomatic LSS with NC. In most studies (n=17), LSS was diagnosed using a combination of clinical assessment such as patient's history and/or physical examination, and findings of magnetic resonance imaging (MRI). Regarding NC, only seven studies described NC as pain, numbness, weakness, or tingling in the lower extremity brought on by lumbar extension, standing, or walking. Based on criteria provided for inclusion of participants (or introduction section when inclusion criteria prevented the definitive identification of LSS subtypes), 974 presented with central LSS, 246 presented with combined central LSS and spondylolisthesis, 66 presented with either central or foraminal stenosis, 54 with either central or lateral stenosis, 49 with either central LSS or a combination of central and foraminal stenosis or lateral stenosis and 14 presented with lateral LSS. Finally, there were 291 patients for which the exact LSS type (e.g. central) was not explicitly described. Mean age of participants ranged from 58 to 76.9 years old across studies. Extracted data regarding population are presented in Supplement Material 2 (*Annexe B de la thèse*).

Quality Assessment

The 24 studies were assessed for quality using the AXIS tool. Two studies (Sigmundsson et al., 2011; Tong et al., 2007) scored between 6 and 10, 14 studies (Conrad et al., 2013; Inoue et al., 2020; Ishimoto et al., 2012; Kim et al., 2011; Kuittinen et al., 2014; Kuwahara et al., 2019; Minetama et al., 2020; Nagai et al., 2014; Özdemir et al., 2015; Pryce et al., 2012; Quack et al., 2019; Schmidt et al., 2017; Tomkins-Lane & Battie, 2013; Zeifang et al., 2008) scored between 11 and 15, and 8 studies (Conway et al., 2011; Drury et al., 2009; Fujita et al., 2019; Garbelotti Jr et al., 2014; Grelat et al., 2019; Igawa et al., 2018; Thornes et al., 2018a, 2018b) scored between 16 and 19. The items from the AXIS tool are reported in Supplement Material 3 (*Annexe C de la thèse*).

Associations

Surprisingly, no study investigated associations between gait pattern characteristics and walking capacity or functional tasks. However, a few studies reported associations between either physical or psychological factors and gait pattern characteristics. Considering that gait pattern characteristics do have a direct impact on walking capacity, these unplanned associations have been extracted and are now presented as a third category of associations along with walking capacity and functional tasks. All reported associations (significant or not) between either physical or psychological factors, and measures of walking capacity, functional tasks or gait pattern characteristics are presented in Supplementary Table 1 (*Annexe D de la thèse*).

There was significant heterogeneity within both PROMs and objective measures used to assess physical and psychological factors for each category of outcome measures among the studies. Figure 2.2 illustrates the range of outcome measures reported.

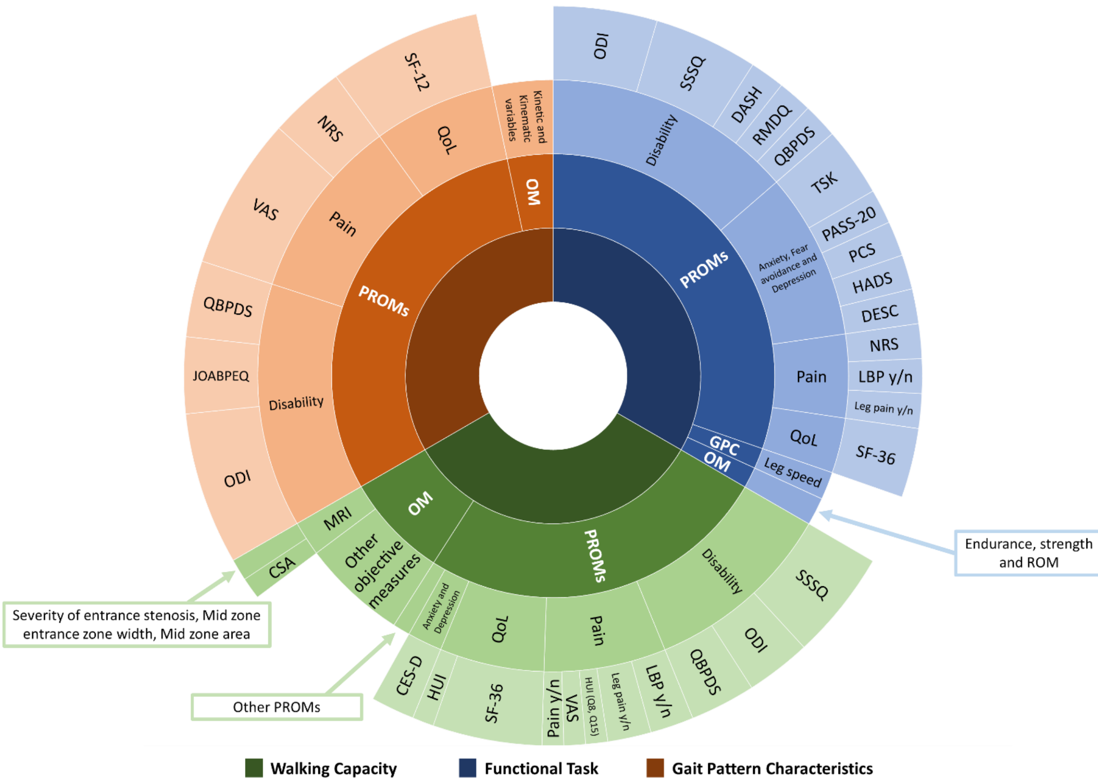

Figure 2.2 - Range and proportion of tools used to assess physical and psychological factors associated with walking capacity, functional task, and gait pattern characteristics.

PROMs = Patient-Reported Outcome Measures, OM= Objective Measures, GPC= Gait Pattern Characteristics, QoL= Quality of Life, MRI= Magnetic Resonance Imaging, ODI= Oswestry Disability Index, SSSQ= Swiss Spinal Stenosis Questionnaire, DASH= Disability of the Arm, Shoulder and Hand questionnaire, RMDQ= Roland-Morris Disability Questionnaire, QBPDS= Quebec Back Pain Disability Scale, TSK= Tampa Scale of Kinesiophobia, PASS-20= Pain Anxiety Symptoms Scale, PCS= Pain Catastrophizing Scale, HADS = Hospital Anxiety and Depression Scale, DESC= Rasch-based Depression Screener, NRS= Numeric Rating Scale, LBP= Low Back Pain, SF-36= 36-item Short Form Health Survey, SF-12= Medical Outcomes Short-Form 12, HUI= Health Utilities Index Mark 3, VAS= Visual Analog Scale, CES-D= Center of Epidemiological Studies Depression Scale, CSA= Cross-sectional area, JOABPEQ= Japanese Orthopedic Association Back Pain Evaluation Questionnaire

As a large range of associated factors were retrieved from the 24 studies, only significant associations with walking capacity, functional tasks and gait pattern characteristics are reported herein. Additional details regarding non-significant associations are reported in Supplement Material 4 (*Annexe E de la thèse*). All associations are illustrated in Figure 2.3.

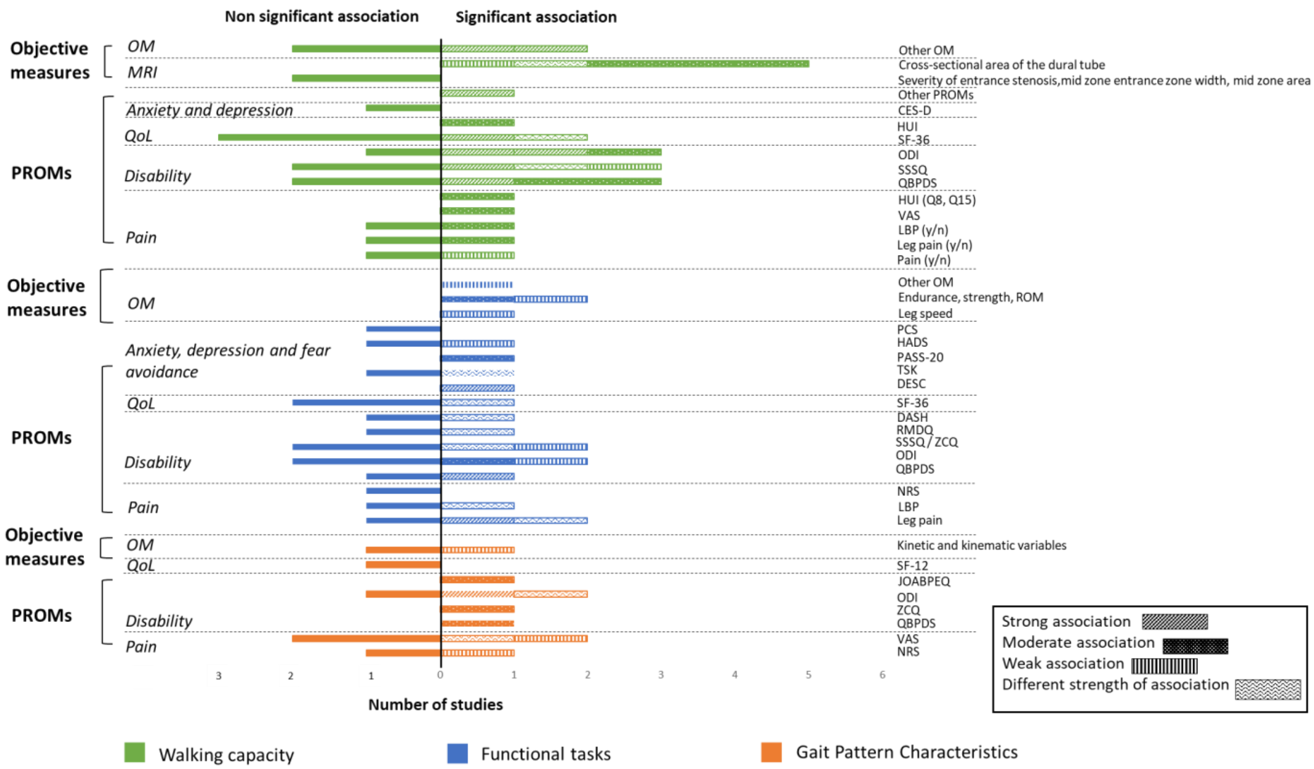

Figure 2.3 - Associations between walking capacity, gait pattern characteristics, functional tasks and PROMs and objective measures, expressed in number of studies

PROMs = Patient-Reported Outcome Measures, OM= Objective Measures, QoL= Quality of Life, MRI= Magnetic Resonance Imaging, CES-D= Center of Epidemiological Studies Depression Scale, HUI= Health Utilities Index Mark 3, SF-36= 36-item Short Form Health Survey, SF-12= Medical Outcomes Short-Form 12, ODI= Oswestry Disability Index, SSSQ= Swiss Spinal Stenosis Questionnaire, ZCQ= Zurich Claudication Questionnaire, QBPDS= Quebec Back Pain Disability Scale, LBP= Low Back Pain, VAS= Visual Analog Scale, ROM= Range of Motion, PASS-20= Pain Anxiety Symptoms Scale, PCS= Pain Catastrophizing Scale, HADS = Hospital Anxiety and Depression Scale, TSK= Tampa Scale of Kinesiophobia, DESC= Rasch-based Depression Screener, DASH= Disability of the Arm, Shoulder and Hand questionnaire, RMDQ= Roland-Morris Disability Questionnaire, NRS= Numeric Rating Scale, JOABPEQ= Japanese Orthopedic Association Back Pain Evaluation Questionnaire

Physical and psychological factors associated with walking capacity

<u>PROMs</u>

Pain

Overall, conflicting results were found based on the four studies reporting on the association between leg and/or back pain and walking capacity (distance or time). More specifically, Ishimoto et al. reported a weak positive association between symptomatic LSS (lower limb and/or buttock pain) and the 6-m walking time at maximal pace (vs usual pace) (Ishimoto et al., 2012). Tomkins-Lane and Battie (2013) reported moderate positive correlations between walking distance and number of years with back pain and number of years with leg pain. They also reported moderate negative associations between walking capacity and intensity of leg pain before walking, and the items 8 (pain and discomfort over the past week affecting activities) and 15 (pain and discomfort over the past week requiring medication) of the Health Utilities Index Mark 3 (HUI) questionnaire (Tomkins-Lane & Battie, 2013). The other two studies did not report significant associations between pain and walking capacity (Conway et al., 2011; Tong et al., 2007).

Disability

Overall, conflicting results were found based on the six studies reporting on the association between disability and walking capacity (distance or time).

Three studies (Conway et al., 2011; Grelat et al., 2019; Tong et al., 2007) measured disability using the QBPDS, of which only one showed a strong negative correlation between the total QBPDS score and walking distance (Conway et al., 2011). When looking at the questionnaire individual subscales, four (walk, reach, run and groceries) were strongly and negatively correlated with total walking distance and one (stand) was strongly and negatively correlated with walking time to first symptoms.

All four studies using the SSSQ found moderate to strong negative correlations with walking capacity (Conway et al., 2011; Drury et al., 2009; Thornes et al., 2018a; Tomkins-Lane & Battie, 2013). Specifically, Drury et al. reported a moderate association between walking distance and the SSSQ total score. Regarding the SSSQ individual subscales, results among the four studies were conflicting. Drury et al. reported moderate to strong negative correlations between walking capacity and the physical function and each component of the symptom subscale (pain, sensory and neuroischemic) (Drury et al., 2009). Thornes et al. reported a moderate negative correlation between walking capacity and the physical function subscale and Tomkins and Battie reported a moderate negative correlation between walking capacity and the symptom subscale. However, two studies also reported no correlation between walking capacity and some SSSQ subscales (Conway et al., 2011; Thornes et al., 2018a).

All three studies using the ODI found weak to strong correlations with total walking distance (Conway et al., 2011; Grelat et al., 2019; Tomkins-Lane & Battie, 2013). However, Conway et al. reported a non-significant correlation between the ODI and walking capacity regarding time to first symptoms (Conway et al., 2011).

Quality of life

Overall, conflicting results were found based on the five studies reporting on the association between quality of life and walking capacity (distance or time) (Conway et al., 2011; Drury et al., 2009; Grelat et al., 2019; Özdemir et al., 2015; Tomkins-Lane & Battie, 2013).

All three studies reporting on QoL using the SF-36 reported at least one significant associations of varying strength with walking distance (Conway et al., 2011; Drury et al., 2009; Özdemir et al., 2015). Of these, one reported a strong positive correlation between SF-36 and walking distance (Drury et al., 2009). When looking at the questionnaire individual subscales, three studies reported moderate to strong positive correlations between the physical functioning (PF) subscale and walking distance (Conway et al., 2011; Drury et al., 2009; Özdemir et al., 2015). Moreover, Drury et al. (2009) reported moderate positive correlations between four of the subscales (role physical, bodily pain, general health index and social functioning) and walking distance whereas they reported a weak positive correlation between the vitality subscale and walking distance. Out of the two studies reporting on the association between the mental health subscale and walking distance (Drury et al., 2009; Özdemir et al., 2015), only one reported a moderate positive correlation (Özdemir et al., 2015). One study used a shorter version of the SF-36 (SF-12) and reported no significant association (Grelat et al., 2019). Finally, one study reported a moderate positive correlation between health-related QoL using the HUI questionnaire and walking capacity(Tomkins-Lane & Battie, 2013).

Anxiety and depression

One study assessed depression using the CES-D and reported no significant correlation between depression status and walking distance (Zeifang et al., 2008).

Estimated walking distance

One study assessed estimated walking distance and showed a strong significant correlation between this estimated and measured walking distances (Conway et al., 2011).

<u>Objective outcome measures</u>

MRI findings

Overall, conflicting results were found based on the three studies reporting on the association between MRI characteristics and walking capacity (distance or time) (Kuittinen et al., 2014; Sigmundsson et al., 2011; Zeifang et al., 2008). One study reported a negative association between the cross-sectional area of the dural tube measured at L1/L2 and walking distance (Zeifang et al., 2008). Two studies reported no significant correlation between MRI findings and walking distance (Kuittinen et al., 2014; Sigmundsson et al., 2011).

Other objective outcome measures

Overall, conflicting results were found based on the six studies reporting on the association between other objective measures and walking capacity (Conway et al., 2011; Inoue et al., 2020; Nagai et al., 2014; Tomkins-Lane & Battie, 2013; Zeifang et al., 2008). Specifically, one study reported a strong positive correlation between maximum time of continuous activity per day over a 7-day period (at a minimum of low intensity) and walking distance, (Conway et al., 2011) and another study reported a moderate positive correlation between daily step count and walking distance (Minetama et al., 2020). One study showed a moderate negative correlation between balance problems and walking capacity (Tomkins-Lane & Battie, 2013). One study reported a negative association between BMI and walking distance, and a positive association between functional status (combination of tests) and walking distance (Zeifang et al., 2008). One study reported a strong negative correlation between trunk postural sway and maximum walking distance (Nagai et al., 2014). Two of these studies also showed no significant association between other objectives measures and walking capacity (Conway et al., 2011; Nagai et al., 2014). Finally, one study reported a moderate negative correlation between handgrip strength and walking time and a weak positive correlation between handgrip strength and walking distance (Inoue et al., 2020).

Physical and psychological factors associated with functional tasks

<u>PROMs</u>

Pain

Overall, conflicting results were found based on the four studies reporting on the association between pain outcomes and functional tasks (Conway et al., 2011; Ishimoto et al., 2012; Minetama et al., 2020; Pryce et al., 2012). More specifically, strong positive correlations were found between leg pain severity and overall activity per day measured with an activity monitor, as well as maximum time of continuous activity per day (Conway et al., 2011).

Pryce et al. reported moderate to strong correlations between back pain (intensity and related function), leg pain (related function) and physical activity (volume and duration). Physical activity intensity was not associated with either back or leg pain intensity and function. They also reported moderate to strong negative correlations between back or leg pain intensity and bout length or maximum bout length of meaningful activity. However, back pain intensity was negatively correlated with bout length and maximum bout length only at meaningful physical activity intensity, while leg pain intensity was only correlated at moderate intensity (between 1.5 and 2.99 METs) (Pryce et al., 2012). All other associations between pain and functional tasks were non-significant (Ishimoto et al., 2012; Minetama et al., 2020).

Disability

Overall, conflicting results were found based on the five studies reporting on the association between disability and functional tasks (Conway et al., 2011; Kim et al., 2011; Minetama et al., 2020; Pryce et al., 2012; Thornes et al., 2018a, 2018b).

Conway et al. reported strong negative correlations between disability, measured using the run subscale of the QBPDS questionnaire, and overall activity per day, as well as between disability and time of continuous activity. All other correlations between the QBPDS and functional tasks were not significant (Conway et al., 2011).

Four studies conducted correlation analyses between the ODI and functional tasks (Conway et al., 2011; Kim et al., 2011; Pryce et al., 2012; Thornes et al., 2018b). Results from Pryce et al. (2012) showed moderate to strong negative correlations between disability and physical activity volume, intensity, and duration. They also showed moderate to strong negative correlations between disability and maximum bout length at meaningful intensity and at moderate intensity during ambulatory behavior. The ODI was only correlated with bout length during ambulatory behavior at moderate intensity. Thornes and colleagues reported an association between stability in gait and the total ODI score. All other associations between ODI and functional tasks were not significant (Conway et al., 2011; Kim et al., 2011).

The RMDQ was used in the study by Pryce et al. (2012) to assess disability. In this study, authors reported moderate to strong negative correlations between disability and physical activity volume, intensity and duration. They also reported moderate to strong negative correlations between disability and bout length and maximum bout length during ambulatory behavior (Pryce et al., 2012).

Three studies reported on the correlation between the SSSQ (also known as the Zurich Claudication Questionnaire (ZCQ)) total score or subscales and functional tasks (Minetama et al., 2020; Thornes et al., 2018a, 2018b). The results of Thornes et al. (2018a) showed negative moderate correlations between the symptoms subscale and the 30-second Sit-to-Stand test, and the One Leg Stance test while they showed a positive moderate correlation between the symptoms subscale and the stair climbing test. The authors also reported a moderate correlation between the physical function subscale and stair climbing (Thornes et al., 2018a) and a weak association between the physical function subscale and the score of the Mini-BESTest (Thornes et al., 2018b). However, Minetama et al. (2020) reported non-significant correlations between daily step count and the symptom subscale or the physical function subscale of the SSSQ.

Finally, Price et al. reported moderate to strong negative correlations between disability measured using the DASH questionnaire and physical activity volume, intensity and duration, as well as bout length and maximum bout length during ambulatory behavior (Pryce et al., 2012).

Quality of life

Overall, conflicting results were found based on the two studies reporting on the association between QoL and functional tasks (Pryce et al., 2012).

Pryce et al. reported moderate to strong positive correlations between the SF-36 total score and physical activity (volume, duration, intensity), and ambulatory behavior (bout length and maximum bout length) at both meaningful and moderate intensity (Pryce et al., 2012). Further details about correlations between functional task and all SF-36 subscales are presented in table 2.

Depression, anxiety and fear avoidance

Two studies reported on the association between either depression or fear avoidance and functional tasks (Minetama et al., 2020; Quack et al., 2019). Depression was strongly and negatively correlated with the patient's participation in social, daily and work-related activities using the Aachen Activity and Participation Index (AAPI). Depression was also moderately and positively correlated with lower extremity function using the RehaCAT lower extremity subscale and with activities of daily living when using the RehaCAT lower extremity subscale. Minetama et al. (2020) reported moderate negative correlations between daily step count and the total score, the cognitive anxiety subscale, the escape/avoidance subscale, and the fear subscale of the Pain Anxiety Symptom Scale (PASS-20). The authors also reported a weak negative correlation between daily step count and depression as measured by the Hospital Anxiety and Depression Scale (HADS) but no correlation with anxiety also measured by the HADS (Minetama et al., 2020).

Furthermore, two studies reported on the association between kinesiophobia and functional tasks (Minetama et al., 2020; Quack et al., 2019). The somatic focus subscale of the TSK was strongly and positively correlated with the RehaCAT lower extremity subscale while the activity avoidance subscale was moderately and positively correlated with the RehaCAT lower extremity subscale. The score of the RehaCAT activities of daily living subscale was moderately and positively correlated with the somatic focus and the activity avoidance subscales of the TSK (Quack et al., 2019). The correlation between daily step count and kinesiophobia was not significant (Minetama et al., 2020).

Finally, one study reported a correlation between daily step count and pain catastrophizing as measured with the Pain Catastrophizing Scale (PCS) (Minetama et al., 2020). However, the correlations between each subscale of the PCS were not significantly correlated with daily step count.

Objective outcome measures

Other objective outcome measures

Two studies reported on the associations between other objective measures and functional tasks performance. Schmidt et al. (2017) reported weak associations between either trunk extensor muscle endurance, leg strength asymmetry or leg speed during a leg press and the Short Physical Performance Battery score. They also reported weak associations between either trunk extensor muscle endurance, knee flexion ROM or knee extension strength asymmetry and the Habitual Gait Speed test, and a weak association between leg strength and the Chair Stand test (Schmidt et al., 2017). Finally, one study reported a moderate negative correlation between handgrip strength and walking steps (Inoue et al., 2020).

Physical and psychological factors associated with gait pattern characteristics

PROMs

Pain severity

Overall, conflicting results were found based on the three studies reporting on the association between pain severity and gait pattern characteristics (Conrad et al., 2013; Garbelotti Jr et al., 2014; Kuwahara et al., 2019). To assess pain severity, one study used the 11-point Numeric Rating Scale (NRS) and two studies used a VAS (Conrad et al., 2013; Garbelotti Jr et al., 2014; Kuwahara et al., 2019). Only back pain, measured using the NRS, was weakly and positively correlated to walking velocity (Conrad et al., 2013). Regarding leg pain, Kuwahara et al. (2019) reported a moderate negative correlation between leg pain and peak trunk tilt during walking (Kuwahara et al., 2019). Other significant correlations were reported between pain severity (location unspecified) and width of base of support, the Gait Disability Index (GDI), peak lumbar tilt pre- and post-walking, and changes in pelvis tilt variation during stance (Garbelotti Jr et al., 2014). All other gait pattern characteristics measured in these studies were non-significant.

Disability

Overall, conflicting results were found based on the three studies reporting on the association between disability and gait pattern characteristics (Conrad et al., 2013; Fujita et al., 2019; Grelat et al., 2019).

Out of two studies using the ODI to assess disability (Conrad et al., 2013; Grelat et al., 2019), one study reported strong positive correlations between disability and gait velocity and step length, as well as a weak positive correlation between disability and base of support (Conrad et al., 2013). The same authors also reported that other gait pattern characteristics such as cadence, lumbar proprioception (except for left lateral bending) and ROM were not correlated with the ODI score. The second study reported a strong correlation between disability and free walking speed (Grelat et al., 2019).

One study reported a moderate correlation between disability, measured using the QBPDS, and free walking speed(Grelat et al., 2019).

Finally, one study reported weak positive associations between disability, measured using the JOABPED total score or its individual subscales, and short stride when walking (Fujita et al., 2019).

Quality of life

One study reported non-significant correlations between QoL using the SF-12 and gait pattern characteristics (Conrad et al., 2013).

<u>Objective outcome measures</u>

Other objective outcome measures

One study reported weak positive correlations between anterior trunk flexion angle during walking and step length as well as maximum ankle plantar flexion moment (Igawa et al., 2018).

DISCUSSION

This systematic scoping review explored the current state of scientific knowledge regarding the associations between physical or psychological factors and walking capacity in patients with LSS. Results show that physical factors are more commonly studied than psychological factors with 22 studies reporting on physical factors and three reporting on psychological factors. The systematic scoping review highlighted the use of a wide range of PROMs and objective measures, with disability being the most frequently reported outcome measure followed by pain. Among objective measures, reported tools were heterogenous with most used in no more than one study. A third outcome category (gait pattern characteristics) was added following data extraction given that no study directly assessed gait pattern characteristics in relation to walking capacity. Considering the impact of gait pattern characteristics on decreased walking capacity, associations between physical or psychological factors and gait pattern characteristics were reported. Results among studies were conflicting regarding associations between PROMs and either walking capacity, functional tasks or gait pattern characteristics. Results were also conflicting for associations between objective measures and either walking capacity, functional tasks or gait pattern characteristics. Some outcome measures, however, were clearly associated with several measures related to walking capacity. For instance, walking capacity was significantly associated with pain outcomes, disability, estimated walking distance and cross-sectional area of the dural tube in the lumbar spine (L1/L2). Among the included studies, functional tasks were associated with physical factors such as lower back and upper limb disability, and lower limb endurance, strength, ROM and speed. Strong significant correlations were also found between gait pattern characteristics (speed and stride) and disability outcomes. These results clearly highlight the intricate and heterogeneous presentation of symptomatic LSS.

Conflicting results can possibly be explained by the heterogeneity of walking capacity tests used across studies. Most tests were not validated in people with symptomatic LSS (Drury et al., 2009; Grelat et al., 2019; Ishimoto et al., 2012; Kim et al., 2011; Kuittinen et al., 2014; Nagai et al., 2014; Thornes et al., 2018a; Tong et al., 2007), although a few were validated in elderly individuals (Grelat et al., 2019; Ishimoto et al., 2012; Kim et al., 2011). Out of nine walking tests, only four (Self-Pace walking tests, Shuttle walking test, Treadmill walking test and 6-meter walking test) were validated and/or reliable specifically for patients with LSS (see Supplement 5 for further details – *Annexe F de la thèse*). Further studies are needed to assess the validity of commonly used walking tests in patients with symptomatic LSS. Validated walking test for patient with LSS should be used to better understand walking limitations caused by LSS.

The most commonly reported psychological factor was depression and results were conflicting. The Rasch-based Depression Screener (DESC) and PASS-20 questionnaire were associated with decreased performance in functional tasks. Other psychological factors including anxiety, depression and kinesiophobia were either not associated or showed conflicting evidence of association with walking capacity, functional tasks, or gait pattern characteristics. A comprehensive assessment of walking capacity combined with a better knowledge of the physical and psychological factors associated with walking capacity will help health care professionals identified targeted rehabilitation strategies.

The present systematic scoping review highlighted conflicting results among studies reporting on the association between PROMs or objectives measures and measures related to walking capacity (i.e. walking capacity, functional tasks and gait pattern characteristics). The wide range of questionnaires used to assess the same outcome could also explain some of these conflicting results. For instance, disability was reported using 6 different questionnaires, with only one being specifically validated for LSS (the SSSQ). Low back pain and/or leg pain were also reported among studies using different tools (presence or absence thereof, VAS, NRS or HUI). The most commonly reported QoL questionnaire used was the SF-36. However, its association with walking capacity and functional tasks was unclear. On the other hand, the HUI, also used to assess QoL, was associated with greater walking capacity. Objective measures were all different across studies and such heterogeneity impeded our ability to determine whether specific outcome measures are related to walking capacity in patients with LSS. In addition, no study specifically assessed gait pattern characteristics such as stride, walking phases or walking velocity in relation to walking distance or walking time. It seems important to evaluate these characteristics in order to establish if deviations from normal gait pattern are present in patients with symptomatic LSS. Knowing that risk of fall is increased in populations with mobility impairment (Kim et al., 2011), a better understanding of walking gait characteristics that can modify walking capacity is needed to know if these walking parameters can also contribute to an increased risk of fall. As such, slower walking speed seems to be related to increased fear of falling (Chamberlin et al., 2005). Given that some changes in gait pattern normally occur with aging, it is important to know if additional changes are brought on by symptomatic LSS.

Another possible explanation for the conflicting results is the lack of a clear definition for LSS in the studies. Diagnostic ascertainment for inclusion of participants was not clearly mentioned in some studies. Furthermore, many studies reported only the range of included LSS subtypes among participant instead of providing the exact number of individuals per subtype. They also did not clearly describe affected levels.

Clinical implications

For clinicians, understanding which walking parameters are modified in patients with LSS would provide new insights on the consequences brought on by LSS on gait. If any of these parameters are identified as associated factors, clinicians will be able to establish a treatment plan and monitor clinical evolution more closely over time. Clinicians are also aware that the patient's psychological state can have an impact on the prognosis of musculoskeletal disorders. For instance, patients with LSS reporting depression or at high risk of developing depression show poorer outcomes over time (Hébert et al., 2020). However, more studies are needed to inform the possible implications of psychological status on walking-related functions in patients with LSS.

SPWT was the most used test to assessed walking capacity in patients with LSS and was the only reliable and validated one for this specific population. Results from the present systematic scoping review suggest that subjective evaluation tools such as the SSSQ and ODI were the disability-related questionnaires the most used and for which there were many significant associations with the three domains (walking capacity, functional tasks and gait pattern characteristics). Regarding QoL, the most used questionnaire was the SF-36 but results were conflicting across studies. MRI findings (cross-sectional area) were associated with walking capacity. Regarding objective measures and psychological factors, current evidence suggests that further studies are needed to be able to better formulate recommendations for clinicians. Exploring other biomechanical walking parameters such as minimal toe clearance, speed, simple and double stance and step width can be interesting indicators to consider when assessing walking capacity in future studies.

Strengths and limitations

To our knowledge, this is the first systematic scoping review to assess physical and psychological factors associated with walking capacity in patients with LSS. One strength of this review is that every step was consistent with the current standards for conducting a systematic scoping review (Levac et al., 2010; Peters et al., 2015). It is not, however, without limitation. The first limitation of our study was the low number of studies that provided a direct evaluation of walking capacity. Only studies published in English, French or Spanish were considered for this scoping review. We cannot rule-out that additional relevant evidence may have been published in other languages. Moreover, most of the studies did not specify the level and location of the LSS limiting the clinical interpretation of the results with regards to distinction of LSS subtypes.

CONCLUSION

The present systematic scoping review allowed to identify physical and psychological factors that are associated with walking capacity in patients with symptomatic LSS. However, a large number of associations reported between walking capacity and physical or psychological factors were conflicting especially when correlated directly with the assessment of walking capacity.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions: MH was the principal investigator of this scoping review; she participated in the study design, literature search, data extraction, results formatting, as well as the manuscript writing. JD participated in the data extraction and results formatting. AAM and MD participated in the study design, overall supervision of the project, manuscript writing and revision. AAM was also involved in the screening process as the third person to obtain consensus (sorting and quality rating). All authors read and approved the final manuscript.

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Chapitre 3 – Article 2, Evaluation of gait pattern characteristics in adults over 50 years of age

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Résumé

Introduction et objectif: La marche joue un rôle important dans le maintien de l'indépendance fonctionnelle. Comme les conditions chroniques se mêlent généralement au processus normal de vieillissement de l'individu, il est important de comprendre les changements attribuables à l'âge pouvant être observés au niveau des caractéristiques du patron de marche. L'objectif de cette étude était de décrire et de comparer les caractéristiques du patron de marche chez les personnes âgées de 50 ans et plus en fonction de l'âge et du sexe.

Methodologie: Trente-quatre adultes âgés entre 50-59 ans, 38 âgés entre 60-69 ans et 28 âgés de 70 ans ou plus ont été recrutés. Les participants devaient effectuer un test de marche sur une distance de 30 mètres (15 mètres à l'aller et 15 mètres au retour) à leur vitesse de préférence. Les caractéristiques biomécaniques du patron de marche ont été mesurés à l'aide de capteurs inertiels pendant le test de marche. Les comparaisons entre les groupes d'âge ont été réalisées à l'aide de l'ANOVA à un facteur ou du test de Kruskal-Wallis, tandis que les comparaisons entre les hommes et les femmes ont été effectuées à l'aide du test-t pour groupes indépendants ou du test de Mann-Whitney.

Résultats: Les résultats ont montré que la longueur de foulée, la vitesse et le dégagement minimal des orteils diminuaient avec l'âge (ps<0,01), tandis que la cadence et le dégagement maximal du talon étaient similaires entre les groupes d'âge (ps>0,05). En ce qui concerne les différences entre les sexes, les hommes avaient une cadence plus faible, une longueur de foulée plus grande et un dégagement maximal du talon plus élevé que les femmes (ps<0,04), tandis que la vitesse et le dégagement minimal des orteils étaient similaires entre les sexes (ps>0,05).

Conclusion: Cette étude a identifié les différences dans les caractéristiques du patron de marche entre les différents groupes d'âge et les sexes chez les adultes de plus de 50 ans.

Implications: Il est essentiel d'avoir de données de référence sur les caractéristiques du patron de marche prenant en compte les changements liés à l'âge, afin d'évaluer la marche chez les adultes âgés et de mieux comprendre les écarts anormaux que pourraient présenter certaines populations.

Mots-clés: Analyse de la marche, âge moyen, personnes âgées, vieillissement

ABSTRACT

Background/objective: Walking plays a crucial role in the maintain of functional independence. Since chronic conditions often overlap with normal aging processes, it is important to thoroughly understand the changes in gait pattern characteristics that are attributable to healthy aging. The objective of this study was to describe and compare gait characteristics, according to age and sex, in adults over 50 years of age.

Methods: Thirty-four adults aged 50–59, 38 aged 60–69, and 28 aged 70 and above were recruited. Participants had to walk on a 30-meter round trip at self-selected speed. Biomechanical characteristics of gait were measured using wearable inertial measurements units. Comparisons between age groups for were conducted using one-way analysis of variance or Kruskall-Wallis test while comparisons between males and females were conducted using t-test for independent groups or Mann-Whitney test.

Results: Results showed that stride length, stride velocity and minimal toe clearance decreased with increasing age ($ps<0.01$) while cadence and maximal heel clearance parameters were similar across all age groups ($ps>0.05$). Regarding sex differences, males had a lower cadence, a longer stride and a higher maximal heel clearance than females ($ps<0.04$), while stride velocity and minimal toe clearance were similar between sexes ($ps>0.05$).

Conclusion: This study identified the differences in gait characteristics between age groups and sexes in adults over 50 years of age.

Significance/implications: Having normative data of gait patterns characteristic that consider age-related changes is crucial for the evaluation of gait in older adults to better understand abnormal deviations of gait.

Keywords: Gait analysis, middle-aged, older adults, aging

INTRODUCTION

Walking is one of the most prevalent and preferred forms of physical activity performed by older adults (Dawson et al., 2007; DiPietro, 2001). Beyond being a recreational activity, walking is also considered a mode of active transport (Herbolsheimer et al., 2020). As a widely practiced low-intensity activity in older adults (Valenti et al., 2016), walking plays a crucial role in maintaining functional independence (Aboutorabi et al., 2016; Beauchet et al., 2017). However, the walking capacity (Pirker & Katzenschlager, 2017; Winter et al., 2010), which refers to the ability of an individual to move and perform daily tasks, can be impaired in older adults as many of them live with chronic diseases or musculoskeletal disorders (Prince et al., 2015). Given this, improving physical function (e.g. walking capacity) is commonly identified as a key target in the treatment plan of many chronic health conditions, such as cardiovascular diseases (Dobkin, 2005; Forman et al., 2017), Parkinson (Ni et al., 2018) and osteoarthritis (Brophy & Fillingham, 2022). In those chronic conditions, a decline in walking capacity is often observed, along with changes in gait pattern characteristics such as a walking speed and step length (Shimada et al., 2022; Verghese et al., 2009). These two gait pattern characteristics are frequently evaluated, and their decline is recognized as an indicator of risk of adverse outcomes such as falls and disability (Shimada et al., 2022; Verghese et al., 2009). Accordingly, there is a need to better understand changes in gait pattern characteristics attributable to chronic conditions to help clinicians in tailoring interventions more effectively. Since chronic conditions often overlap with normal aging processes, it is important to thoroughly understand the changes in gait pattern characteristics that are attributable to healthy aging.

Aging is well known to be associated with several physiological changes, particularly in the sensorimotor system (Aboutorabi et al., 2016; Beauchet et al., 2017; Yoshimura et al., 2020). Regarding gait pattern characteristics, current evidence indicates a decrease in step length and an increase of temporal characteristics, such as step time, stride time, stance time, swing time and double support time with increasing age while step width remains stable (Herssens et al., 2018). A recent scoping review reported similar changes in addition to reporting a reduction in gait symmetry with increasing age (Aboutorabi et al., 2016). Furthermore, other previous studies showed a decrease in cadence with increasing age (Aboutorabi et al., 2016; Laufer, 2005; Thaler-

Kall et al., 2015). Since most chronic diseases and musculoskeletal conditions that affect walking, such as Parkinson's disease and spinal stenosis, are more prevalent in adults over 50 years old (Jensen et al., 2020; Pringsheim et al., 2014), including middle-aged individuals is important for understanding age-related changes in gait (Frimenko et al., 2015). A recent systematic review highlighted the important gap in gait pattern characteristics in middle-aged individuals (Herssens et al., 2018). To date, changes in gait pattern characteristics have mostly been studied by comparing the gait pattern of young adults (18-50 years old) with that of older pain-free adults (over 65 years old) or between specified decades (e.g., 60s, 70s and 80s) (Chung et al., 2023; Frimenko et al., 2015; Hollman et al., 2011; Ostrosky et al., 1994). Even if these comparisons provided insights about the differences in gait pattern characteristics observed in different age groups, they do not provide information about the onset of aging on gait pattern characteristics in middle-aged individuals (50 to 65 years old). This age group represents an important and growing subgroup of the population (Newmyer et al., 2022). A better understanding of gait pattern characteristics among individuals in this age group could contribute to the development of more impactful strategies to promote healthy aging and maintain walking capacity and autonomy which will enhance the quality of life of middle-aged individuals as they transition into their later years (Herssens et al., 2018). In addition, having normative data for all gait pattern characteristics in this age group could help identify early signs and changes specific to age-related chronic conditions.

Furthermore, considering age-related changes in gait, it is also essential to address the sex differences. Current evidence indicate that males and females have similar preferred speed when walking and that there are sex differences in cadence, stride length and gait cycle length (Ko et al., 2011). However, sex differences for more specific gait pattern characteristics such as gait subphases, peak angle velocity and clearance parameters have not been assessed in middle-aged and older adults.

The objective of this study was to describe and compare gait characteristics, according to age and sex, in adults over 50 years of age. We hypothesized that cadence, stride length, stride velocity and clearance variables would all decrease with age. We also hypothesized that, compared to women, cadence would be lower and stride length greater in men, while stride velocity and clearance variables would be similar between both sexes.

METHODS

Study design

This cross-sectional study was conducted at the Université du Québec à Trois-Rivières (UQTR). Recruitment and data collection took place from September 2020 to April 2023.

Participants

One hundred adults were recruited via social media platforms, including Facebook pages and the university institutional website. A post hoc power analysis was conducted using G*Power to determine the statistical power of the study. With a sample size of 100 participants and an effect size of $\eta^2 = 0.153$ for walking velocity, and an alpha level set at 0.05, the calculated statistical power was found to be 0.81.

To be included, participants needed to be at least 50 years old and be able to walk without a walking aid. Participants with low back pain, lower limb pain such as symptomatic knee or hip osteoarthritis, symptomatic disc herniation, vascular claudication, uncontrolled diabetes, and cardiac conditions that can impede walking capacity, such as heart failure or having had a back or lower limb surgery in the last 3 months were excluded from this study. The project received approval from the university Human Research Ethics Board (CER-20-269-07.14) and all experimentations were performed in accordance with the relevant guidelines and regulations. All participants provided informed written consent prior to their participation in the study.

Data collection

Data collection began with a brief history-taking to gather sociodemographic data, such as age, height, weight, sex, leg dominance, number of falls during the previous six months and the presence of comorbidities.

Participants were then asked to complete a walking task that consisted of walking on a 30-meter round trip at self-selected speed. The walking task was performed twice, and participants had a two-minute rest period in a sitting position between the trials. During each trial, biomechanical characteristics of gait were measured using wearable inertial measurements units (IMUs) from Physilog®6 (Gait Up, Lausanne, Switzerland) clipped on the top of each participant's shoes with elastic straps (see figure 3.1). Both inertial sensors were synchronized together and were turned on and off manually before and after each walking trial. Each inertial sensor includes a three-dimensional (3D) accelerometer (± 4g), a 3D gyroscope (± 1000˚/s) with a sampling frequency of up to 512Hz, a magnetic field sensor (± 50mT; 256Hz), and a barometer (0-64 Hz). Inertial sensors have been shown to be reliable and valid tools for walking assessment in healthy adults (Homan et al., 2022; Moufawad el Achkar et al., 2016). During the walking task, both left and right foot information was collected.

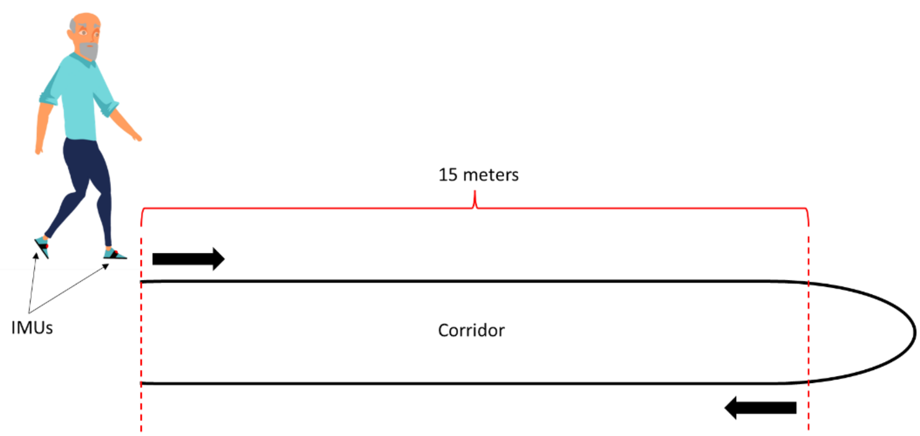

Figure 3.0.1 – Walking Task and IMUs positioning

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Variables

Independent variables

Participants were first divided into three groups according to their age (group 1: 50-59 years old, group 2: 60-69 years old, group 3: ≥ 70 years old). Then, participants were further divided by sex to address our second objective.

Dependant variables

Data from the synchronized Physilog®6 inertial sensors were analyzed using the Gait Analysis Software (v. 5.2, Gait Up Lausanne, Switzerland). All gait characteristics were divided into four categories: general characteristics (cycle duration, cadence, stride length, stride velocity), spatial characteristics (peak angular velocity between maximum heel clearance and minimal toe clearance, heel-strike pitch angle, lift-off angle), temporal characteristics (stance phase which includes loading phase ratio (heel strike), foot-flat ratio (loading response and midstance) and pushing ratio (terminal stance and pre-swing), swing phase and double support), and clearance characteristics (maximum heel clearance, and minimal toe clearance). All gait characteristics are defined in the Appendix 1 (*Annexe G de la thèse*). The first and last two gait cycles (initiation and termination) were discarded as recommended in the user manual of the device and previous studies (Hollman et al., 2011; Jian et al., 1993; Mulas et al., 2021) to ensure that only data associated with the steady state were processed. Values related to turns were also discarded to ensure gait analysis in straight line. Except for gait characteristics that require information from both feet, such as cycle duration, cadence and walking phases, only the recorded data from the dominant leg was used.

Statistical analysis

The normality of data distribution was assessed with the Shapiro-Wilk test and by visual inspection of corresponding histograms for each dependant variable. Proportions were reported for dichotomous variables, while means and standard deviations (SD) were reported for continuous variables. All statistical analyses were performed using IBM SPSS Statistics version 29 (Armonk, NY: IBM Corp.) and the level of significance was set at a p-value of <0.050.

Comparisons between age groups

Comparisons between age groups for male-to-female ratio and comorbidities were conducted using Chi-square analysis. Comparisons between age groups for all sociodemographic data and gait pattern characteristics were conducted using one-way analysis of variance (ANOVA) or

Kruskall-Wallis test. When necessary, the Bonferroni's post hoc test was performed as the post hoc analysis for pairwise comparisons.

Comparisons between sexes

Comparisons between males and females for all gait pattern characteristics were conducted using t-test for independent groups or Mann-Whitney test.

RESULTS

Sociodemographic data

One hundred participants (64 females, 36 males) were recruited for this study and included in the data analyses. All sociodemographic data are presented in Table 3.1. According to Chi-square analysis and based on age groups, the male-to-female ratio was similar between groups (p=0.175). Comparisons between age groups showed that participants from each group were also considered similar in terms of height, weight, and BMI (ps=[0.512-0.778]). Regarding the presence of comorbidities, Chi-square analysis showed no significant difference between age groups (ps=[0.059-0.496]), except for the proportion of participants with high blood pressure, which was higher in group 3 compared to groups 1 and 2 (p=0.022). No falls in the last six months were reported by any of the participants.

Table 3.1. Group comparisons of sociodemographic data

	50-59 yo (n=34) Mean ± SD	60-69 yo (n=38) Mean ± SD	≥ 70 yo (n=28) Mean ± SD	*ANOVA or Kruskal-Wallis*	*Chi-square*	*p-value*
Sociodemographic data						
M : F	8 : 26	16 : 22	12 : 16	-	4.81	0.175
Age (years)	55.38 ± 2.66	63.55 ± 2.85	74.50 ± 3.62	H(2) = 87.757	-	**< 0.001***
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	H(2) = 0.502	-	0.778
Weight (kg)	72.8 ± 15.3	71.9 ± 14.1	68.8 ± 13.0	F(2) = 0.674	-	0.512
BMI (kg/m^2)	26.2 ± 4.8	26.2 ± 4.2	25.6 ± 5.2	H(2) = 0.648	-	0.723
Presence of comorbidities						
High blood pressure (n, %)	6 (17.65)	6 (15.79)	12 (42.86)	-	7.615	**0.022**
Dyslipidemia (n, %)	3 (8.82)	4 (10.53)	8 (28.57)	-	5.659	0.059
Controlled diabetes (n, %)	1 (2.94)	0 (0.00)	3 (10.71)	-	4.970	0.083
Hypothyroidism (n, %)	2 (5.88)	1 (2.63)	3 (10.71)	-	1.869	0.393
Others (n, %)	4 (11.76)	3 (7.89)	5 (17.86)	-	3.380	0.496

M = Males, F = Females, BMI = Body Mass Index, yo = years old, ANOVA = Analysis of variance, SD = Standard Deviation

* Significant difference between group 1 – group 2, group 1 – group 3 and group 2 – group 3 (*ps*>0.001)

Gait pattern characteristics

General gait and spatial characteristics

Comparisons according to age groups

Means and standard deviations of all general and spatial gait characteristics are presented in Table 3.2. Comparisons between age groups regarding general gait characteristics showed no significant differences for cycle duration and cadence (ps=[0.279 – 0.456]). However, significant differences were found between age groups for other general gait characteristics such as stride length and stride velocity (ps<0.001). Bonferroni post hoc analysis showed that individuals ≥ 70 years of age had a significantly shorter stride length and slower stride velocity than individuals from the 50-59 and the 60-69 age groups (ps<0.002). Regarding spatial characteristics, results showed significant differences between age groups for all spatial characteristics (ps=<0.001). Bonferroni post hoc analysis revealed that individuals ≥ 70 years of age had a slower peak velocity, a lower strike angle and a lower lift-off angle than individuals from the 50-59 and the 60-69 age groups (ps=[<0.001 – 0.007]).

Comparisons according to sex

Means and standard deviations of all general and spatial gait characteristics are presented in Table 3.3. When looking at the between-sex comparisons for general gait characteristics, results showed that females had a higher cadence (p<0.001), a shorter stride length (p=0.004) as well as a shorter gait cycle duration (p=0.001) than males. Results also showed no significant difference between females and males for stride velocity (p=0.935). Regarding spatial gait characteristics, results showed that the strike angle was significantly greater in males than in females (p=0.016). All other spatial gait characteristics were considered similar between females and males (ps=[0.071 – 0.456]).

Table 3.2. Group comparisons for general and spatial gait characteristics according to age groups

General and spatial characteristics	**50-59 yo (n=34)**		**60-69 yo (n=38)**		**≥ 70 yo (n=28)**		**ANOVA**	**Kruskal-Wallis**	***p-value***
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**			
Cycle duration (sec)	1.06	0.24	1.03	0.10	1.05	0.10	-	H(2) = 1.570	0.456
Cadence (steps/min)	118.92	10.87	118.94	8.99	115.49	8.75	F(2) = 1.294	-	0.279
Stride length (m)	1.41	0.11	1.42	0.14	1.30	0.13	F(2) = 8.395	-	**< 0.001**$^{\lozenge \dagger}$
Stride velocity (m/s)	1.41	0.16	1.41	0.18	1.26	0.15	F(2) = 8.775	-	**< 0.001**$^{\lozenge \dagger}$
Peak angular velocity (°/sec)	432.93	53.42	431.00	34.58	394.16	86.80	-	H(2) = 24.183	**< 0.001**$^{\lozenge \dagger}$
Strike angle (°)	27.57	5.19	27.93	3.18	23.50	5.43	-	H(2) = 14.961	**< 0.001**$^{\lozenge \dagger}$
Lift-off angle (°)	-73.55	7.59	-74.94	4.88	-68.75	5.17	F(2) = 9.030	-	**< 0.001**$^{\lozenge \dagger}$

yo = years old, SD = Standard Deviation, ANOVA = Analysis of variance

$^{\lozenge}$ = Significant difference between group 1 – group 3 *(ps*=[<0001 - 0.007]), † = Significant difference between group 2 – group 3 (*ps*=<0.001)

Table 3.3. Group comparisons for general and spatial gait characteristics according to sex

General and spatial characteristics	Female (n=64)		Male (n=36)		T-test	Mann-Whitney	*p-value*
	Mean	SD	Mean	SD			
Cycle duration (sec)	1.03	0.19	1.07	0.09	-	U = 1610.00	**0.001**
Cadence (steps/min)	120.63	8.71	113.23	9.49	t(98) = 3.953	-	**< 0.001**
Stride length (m)	1.35	0.12	1.43	0.15	t(98) = -2.960	-	**0.004**
Stride velocity (m/s)	1.37	0.15	1.37	0.22	t(98) = 0.082	-	0.935
Peak angular velocity (°/sec)	423.68	41.75	417.19	86.17	-	U = 901.00	0.071
Strike angle (°)	25.86	4.02	27.83	6.15	-	U = 1488.00	**0.016**
Lift-off angle (°)	-73.10	6.49	-72.09	6.50	t(98) = -0.748	-	0.456

SD = Standard Deviation

Temporal characteristics

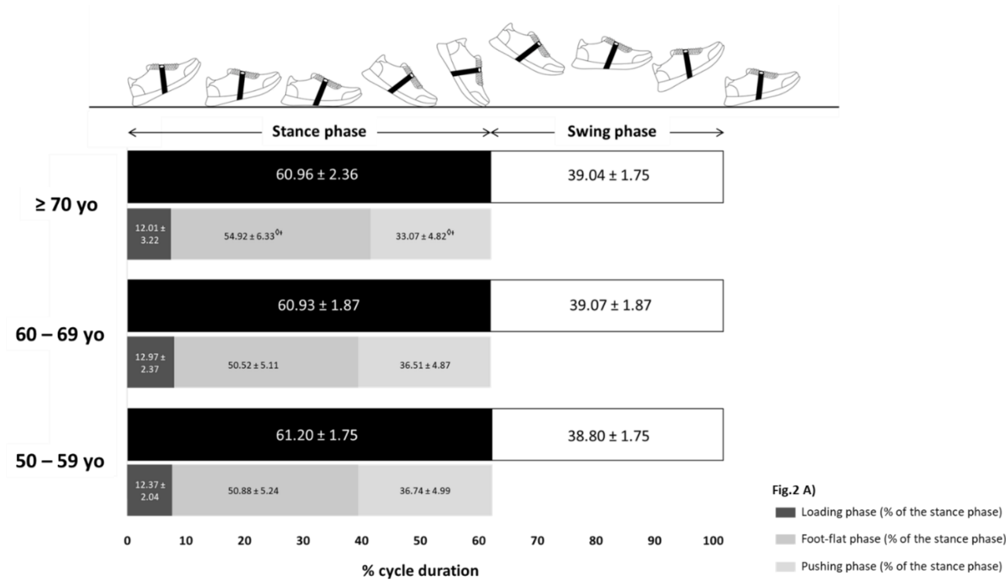
Means and standard deviations of all general and temporal gait characteristics are presented in figure 3.2.

Comparisons according to age groups

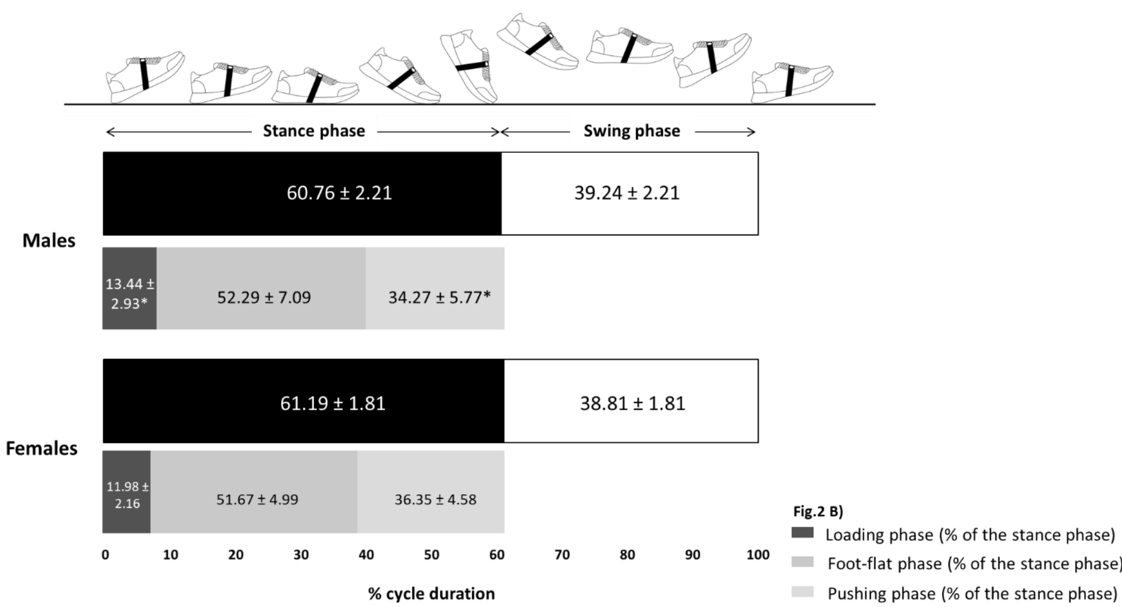
Comparisons between age groups showed no significant difference for stance phase, loading ratio, swing phase and double support phase (ps=[0.133-839]) while there were significant differences for flat-foot ratio and pushing ratio (ps=[<0.001 – 0.003]). Results from the post hoc analyses showed that the flat-foot ratio was higher and that the pushing ratio was lower in individuals ≥ 70 years of age than those in the 50-59 and the 60-69 age groups (ps=[<0.001 – 0.006]).

Comparisons according to sex

Comparisons between sex showed no significant difference between sex for the duration of the stance phase, the swing phase and the double support (ps=[0.295 – 0.372]). When looking at the subphases of walking, results showed that the loading ratio was higher in males than in females (p=0.008) while the pushing ratio was lower in males than in females (p=0.006). There was no significant difference in the flat-foot ratio between sexes (p=0.209).



◊ = Significant difference between group 1 – group 3 (ps=[<0001 - 0.007]), ɫ = Significant difference between group 2 – group 3



yo = years old, * = Significant difference between males and females

Figure 3.2 - Group comparisons regarding temporal characteristics of gait according to age (A) and sex (B)

Clearance characteristics

Comparisons according to age groups

The Kruskal-Wallis analysis showed no significant difference between age groups for max heel clearance ($H(2) = 0.696$, $p=0.706$). Means and standard deviations for the three groups were respectively 0.29 ± 10m, 0.30 ± 0.09m and 0.31 ± 0.13m. Results showed a significant difference between age groups regarding minimal toe clearance ($H(2) = 8.398$, $p=0.015$) and the Bonferroni post hoc analysis revealed that individuals ≥ 70 years lifted their foot higher during the swing phase than individuals from the 50-59 and 60-69 age groups (ps=[0.007-0.017]). In fact, minimal toe clearance was respectively 0.027 ± 0.016m and 0.025 ± 0.010m for groups 1 and 2, while it was 0.034 ± 0.014 for group 3.

Comparison according to sex

Regarding max heel clearance, means and standard deviations were respectively 0.33 ± 0.11m and 0.28 ± 0.10m for males and females. The Mann-Whitney test showed that males had significantly higher max heel clearance ($U = 1958.00$ $p<0.001$) than females while there was no significant difference between sexes for minimal toe clearance ($U = 1349.00$, $p=0.094$) (females = 0.026 ± 0.010 m ; males = 0.033 ± 0.018).

DISCUSSION

The objective of the present study was to describe and compare gait characteristics according to age and sex in adults over 50 years of age using wearable IMUs. As it was hypothesized, stride length, stride velocity and minimal toe clearance decreased with increasing age. However, cadence and maximal heel clearance parameters were similar across all age groups, contrary to our first hypothesis. Regarding sex differences, males had a lower cadence and a longer stride than females, while stride velocity and minimal toe clearance were similar between sexes, which is in accordance with our second hypothesis. However, males had a higher maximal heel clearance than females, contrary to our second hypothesis.

Gait characteristics and age

This study expands on existing knowledge by providing detailed information about general, spatial, temporal, and clearance gait pattern characteristics in a free-walking environment using wearable technology. Additionally, this study includes middle-aged adults, offering new insights into the transition toward the elderly stages of life. Our results indicate that increasing age is associated with changes in gait pattern characteristics, particularly in individuals over 70 years of age. Specifically, most general, spatial, temporal, and clearance gait characteristics were similar between middle-aged adults (50-59 years old) and early elderly individuals (60-69 years old), while significant changes were observed in those over 70 years of age, except for cycle duration, cadence, flat-foot ratio, pushing ratio, and minimal toe clearance.

Our results are consistent with previous findings and confirm that most changes in gait pattern characteristics are observable in advanced age (Beauchet et al., 2017; Hollman et al., 2011). Previous studies on individuals over 70 years of age reported that the decrease in skeletal muscle strength occurring with aging (Faulkner et al., 2007; Lang et al., 2010; Winegard et al., 1996) leads to a reduction of stride length and therefore affects gait velocity (Ziegler et al., 2024). At lower gait velocities, the reduction in stride length is a strategy often used to maintain the same cadence. This strategy, generally referred to cautious gait, is associated with age-related sensory declines (Osoba et al., 2019). The decrease in gait velocity has been previously identified as a risk factor for both falls and frailty (Abellan van Kan et al., 2009). It is then important to highlight that, in our study, individuals over 70 years of age showed a reduction in stride length and gait velocity. However, their mean gait velocity was above the 1.0 m/s threshold for increased risk of falls and frailty.

In addition to contribute to the reduction of stride length and gait velocity, decreases in skeletal muscle strength also contribute to the reduction of the minimal toe clearance during the swing phase. The reduction of this clearance parameter has also been previously reported as an increasing risk factor for falls (Killeen et al., 2017; Perera et al., 2021). In our study, older adults seemed to lift their feet higher than adults in younger age groups which is consistent with previous studies using short walking distance to assess minimal toe clearance (Khandoker et al., 2008; Watanabe, 2018). On longer walking distance, muscle fatigue can occur in older adults which could lead to an unvoluntary decrease in minimal toe clearance values and to an increasing risk of falls. In fact, a previous study showed that the minimal toe clearance decreases with the increase in walking duration in older adults (Watanabe, 2018). It would be interesting to evaluate gait pattern characteristics during a longer walking protocol with additional muscle fatigue measures, such as surface electromyography, to confirm this hypothesis regarding minimal toe clearance and muscle fatigue over longer walking distances.

When looking at characteristics such as strike and lift-off angles, a decrease in those angles was observed in individuals over 70 years of age. Our findings are consistent with previous studies reporting a decrease in plantarflexion during lift-off (Arnold et al., 2014). This suggest that, even if this observation did not take into consideration, the complexity of joint movements in the sagittal plane (hip, knee and ankle), it may still help in the assessment of interventions that impact foot pitch (e.g. foot drop). Peak angle velocity, strike angle and lift-off angle obtained from the Physilog IMUs have been validated against the combination of optical motion capture system and force plates, the actual gold standard for biomechanical assessment (Homan et al., 2022). Knowing that these characteristics change with increasing age, their measurement could provide new insights on the identification of gait deviations in clinical settings.

Regarding walking phases, our study suggested that individuals over 70 years of age have an increased flat-foot ratio duration and a reduced pushing ratio during the stance phase. This finding is coherent with current knowledge as older adults are known to walk with a smaller propulsive activation of the ankle plantar flexor muscles (Browne & Franz, 2018). Since these subphases are directly connected to the stance phase, it would be interesting to assess them during walking protocols at varying velocities to determine how these subphases can be affected by changes in speed.

Overall, our results showed that adults of middle-aged (50-59 years old) had similar gait pattern characteristics to adults aged between 60 and 69 years old and that most changes occured after 70 years old. Our findings also highlight the importance of monitoring gait characteristics across different stages of aging as they reveal critical insights into how aging affects mobility and can inform targeted conservative interventions such as exercises interventions to maintain functional independence and reduce the risk of falls in older adults.

Gait characteristics and sex

The results of the present study showed that there are some differences between males and females regarding general, spatial, temporal, and clearance gait pattern characteristics. Our findings showed that both males and females walked at the same preferred speed and that females had higher cadence, shorter stride length and shorter gait cycle are in accordance with previous studies that took place with both young and older adults (Bruening et al., 2015; Ko et al., 2011). When looking at clearance characteristics of gait, our results showed that males are walking with a longer stride length, while maintaining a minimal toe clearance. Both males and females had similar minimal toe clearance values. As our results are consistent with what has been reported in laboratory settings (Espinoza-Araneda et al., 2022), wearable technologies such as IMUs seem to be interesting to assess gait pattern characteristics. By using such technology in clinical settings, clinicians can be more aware of changes in minimal toe clearance values and prevent future falls. The results of our study also offer additional data on walking subphases such as loading ratio, flat-foot ratio, and pushing ratio, as well as characteristics on peak angle velocity, strike angle, and lift-off angle in both older males and females measured with IMUs. Overall, our results highlight significant sex-based differences in gait characteristics while confirming that both males and females experience similar aging effects. They also highlight the clinical relevance of using wearable IMUs to capture detailed gait patterns and understand sex-specific deviation of gait.

Strength and limitations

To our knowledge, this study is the first to assess all gait pattern characteristics with IMUs in middle-aged adults. First, the inclusion of adults from the middle-age group is important to help characterize changes in gait pattern characteristics that occur with increasing age. Individuals in this age group often experience significant changes, such as retirement, declining health, and shifts in their social circles (Infurna et al., 2020). These factors may contribute to noticeable alteration in gait patterns over time. In this context, IMUs, offer an effective solution for assessing these gait changes across diverse environments, including confined spaces.

This study, however, is not without limitations. Age groups were initially defined using decades. However, it was difficult to recruit individuals over 75 years of age without comorbidities that can negatively affect the gait pattern. Consequently, the older decades were merged to form the group of adults over 70 years old. Further studies should consider including individuals from all age groups (20 to 80 years old) to better understand the aging effects on gait pattern characteristics across the adult life. Another limitation of this study was the walking distance used to assess gait pattern characteristics. The use of a 30-meter round trip on a flat floor may make it difficult to generalize the results to everyday free walking. Further studies using a longer walking distance on different floor types are needed to better capture gait pattern characteristics or gait pattern changes during daily living activities of older individuals. The fact that IMUs do not provide a complete biomechanical analysis of the entire lower limb could also be consider as a limitation in the present study. However, few parameters obtained with IMUs such as the peak angular velocity, can provide about deviation that are related to the kinematic of the lower limb. These information remains clinically interesting. Finally, we did not standardized participants' shoes, but participants were asked to wear comfortable shoes without high heels.

Clinical implications

Having normative data of gait patterns characteristic that consider age-related changes is crucial for the evaluation of gait in older adults to better understand abnormal deviations of gait. Normative data can be useful in the diagnosis and the monitoring of various chronic diseases affecting gait that occur in older adults. In addition, the utilization of IMUs could offer clinicians new tools to capture gait patterns characteristics more efficiently in individuals at a lower cost and in smaller environment when compared to actual gold standard tools used in laboratory facilities (e.g., 3D motion capture systems).

CONCLUSION

This study identified the differences in gait characteristics between age groups and sexes in adults over 50 years of age. The results showed the importance of considering both age and sex when evaluating gait patterns. Having normative data and understanding influence of normal aging and sex will help clinicians to identified gait pattern changes that are linked to chronic conditions. Wearable technologies like IMUs are helpful to capture age-related changes and can also aid in developing targeted interventions for middle-aged and elderly individuals to maintain autonomy and prevent falls.

DECLARATION

Competing interests: The authors declare that they have no competing interests.

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Consent for publication: Not applicable

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Chapitre 4 – Article 3, Comparison of gait parameters between patients with lumbar spinal stenosis causing neurogenic claudication and pain-free older adults: a cross-sectional study

Ce chapitre inclut le troisième article de cette thèse qui a été soumis dans la revue « *BMC Geriatrics* » en 2024.

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Résumé

Contexte : La marche est l'une des formes les plus communes d'activité physique chez la personne âgée et représente une activité essentielle pour le maintien de l'indépendance. Sachant que la sténose spinale lombaire dégénérative (SSL) avec claudication neurogène (CN) est une condition liée au processus de vieillissement et qu'elle engendre une réduction de la capacité de marche, il est important de comprendre comment les paramètres de la marche sont affectés par la SSL. Des études antérieures ont montré que les patients atteints de SSL avec CN présentent une longueur de foulée, une vitesse de marche et une cadence réduites. Toutefois, davantage de recherches sont nécessaires pour étudier d'autres paramètres de la marche, tels que les rapports de phases de marche et les angles du pied, afin d'améliorer les stratégies de gestion et de traitement pour les patients ayant un diagnostic de SSL avec CN.

Objectif : L'objectif de cette étude était de comparer les paramètres du patron de marche entre les patients ayant un diagnostic de SSL avec CN et un groupe de personnes âgées sans douleur.

Résultats : Cent-trente-cinq participants (35 patients ayant un diagnostic de SSL et 100 personnes âgées sans douleur) âgés d'au moins 50 ans ont été recrutés. La collecte de données incluait des informations sociodémographiques telles que l'âge, la taille, le poids, le sexe et l'historique de chutes. Les intensités de douleur au dos et aux jambes ont été mesurées chez les patients ayant un diagnostic de SSL avec CN. Les participants ont répondu à des questionnaires portant sur l'activité physique et la qualité de vie liée à la santé. Les patients ayant un diagnostic de SSL avec CN ont complété un questionnaire supplémentaire sur l'incapacité associé à la SSL. Tous les participants ont réalisé une tâche de marche de 30 mètres avec enregistrement des paramètres de marche à l'aide de capteurs inertiels. La comparaison entre les groupes a montré que la durée du cycle, la phase d'appui, la sous-phase de pied à plat et la phase de double appui étaient plus longues alors que la cadence, la longueur de foulée, la vitesse, les sous-phases de chargement et de poussée, la phase d'oscillation, la vitesse angulaire maximale, l'angle de frappe du talon et l'angle de départ des orteils étaient plus faibles chez les patients ayant un diagnostic de SSL avec CN en comparaison aux personnes âgées sans douleur. Aucune différence significative n'a été observée entre les patients ayant un diagnostic de SSL avec CN et les personnes âgées sans douleur pour les paramètres de dégagement du pied.

Conclusion : Ces résultats suggèrent que les patients ayant un diagnostic de SSL avec CN présentent des altérations des paramètres de la marche, à l'exception des paramètres de dégagement du pied, par rapport aux adultes sans douleur.

Mots-clés : *sténose spinale lombaire, claudication neurogène, paramètres du patron de marche, marche*

Abstract

Background: Walking is the most common form of physical activity for older adults and represents an important activity for maintaining independence. Knowing that degenerative lumbar spinal stenosis (LSS) with neurogenic claudication (NC), an age-related condition, significantly impairs walking capacity, it is important to understand how gait parameters are affected by the condition. Previous studies have found that patients with LSS and NC have reduced stride length, gait speed and cadence. However, more research is needed to investigate additional gait parameters, such as walking phase ratios and foot angles, to improve management and treatment strategies.

Objective: The aim of this study was to compare gait parameters between patients with LSS causing NC and pain-free older adults.

Results: A total of 135 participants (35 patients with LSS causing NC and 100 pain-free adults) aged 50 and above were recruited. Data collection included sociodemographic information such as age, height, weight, sex, and recent falls. Back and leg pain intensities were measured using a visual analog scale in patients with LSS causing NC. Clinical outcomes were measured through questionnaires assessing physical activity and health-related quality of life. Patients with LSS causing NC also completed a questionnaire on LSS-related disability. All participants performed a 30-meter walking task with gait parameters recorded using wearable sensors. Comparison between groups showed that cycle duration, stance phase, foot-flat subphase and double support phase were longer in patients with LSS causing NC than in pain-free older adults, while cadence, stride length, speed, loading and pushing subphases, swing phase, peak angular velocity, heel-strike pitch angle and toe-off pitch angle were lower in patients with LSS causing NC than in pain-free older adults. There was no significant difference between groups for clearance parameters.

Conclusion: These results suggest that degenerative LSS causing NC is negatively associated with altered gait parameters except for clearance parameters compared to pain-free older adults.

Keywords: *lumbar spinal stenosis, neurogenic claudication, gait parameters, walking*

INTRODUCTION

Walking is the most common form of low to moderate-intensity physical activity performed by adults worldwide (Cunningham & Michael, 2004; Erickson et al., 2014; Loukaitou-Sideris, 2020; Sallis, 2015). Walking represents the preferred physical activity of older adults, (DiPietro, 2001) and is recognized as a key indicator of independence and quality of life (Bull & Hardman, 2018; Tudor-Locke et al.). As the population ages, physical activity, including walking, becomes increasingly used in the management of many chronic conditions, especially in age-related conditions such as osteoarthritis and claudication (Lee & Buchner, 2008).

Osteoarthritis of the lumbar spine is an age-related condition that can lead to degenerative lumbar spinal stenosis (LSS), when accompanied by symptoms of spinal nerve compression caused by the narrowing of the lumbar spinal canal (Perruccio et al., 2021; Corinna C. Winter et al., 2010). More specifically, the cardinal symptom of degenerative LSS is neurogenic claudication (NC). This symptom is characterized by unilateral or bilateral discomfort, pain, numbness, or weakness in the buttocks, thighs, or calves that occasionally extend to the lower legs and feet. NC is typically triggered by walking or prolonged standing and relieved by sitting or bending forward (Hartvigsen et al., 2018; Jensen et al., 2020; Katz et al., 2022). Degenerative LSS causing NC impacts walking capacity (Budithi et al., 2017; Katz et al., 2022), and NC-associated walking restrictions have been shown to be greater than in other age-related conditions such as knee or hip osteoarthritis (Corinna C. Winter et al., 2010). Degenerative LSS causing NC is more common in older adults (Koji Otani et al., 2013), and its mean prevalence estimates can reach 39% in clinical populations (Jensen et al., 2020). Degenerative LSS causing NC also represents the most common reason for spine surgery in adults over 65 years of age (Kovacs et al., 2011; Lurie & Tomkins-Lane, 2016). Before considering surgery, individuals with a diagnosis of LSS causing NC must typically have tried conservative treatments such as exercise and manual therapy without success. The primary goal of both conservative and invasive treatments is generally to improve walking capacity while limiting LSS-related symptoms.

A decline in walking capacity is often accompanied by changes in gait patterns. A recent systematic review reported a decrease in general gait parameters such as stride length, gait speed and cadence in patients with LSS causing NC compared with healthy controls (Wang et al., 2022).

However, other gait characteristics such as minimal toe clearance, walking phases duration (stance, swing and double support), peak angular velocity, strike angle and lift-off angle were not covered in the review. A narrative review highlighted the gap in knowledge related to walking phase ratios in patients with LSS causing NC (Natarajan et al., 2022). Studies addressing this gap are needed to better understand gait changes and to improve management strategies, especially with regard to conservative treatments. For example, walking phase ratios can provide information about gait changes that are attributable to compensation due to pain or balance issues. In other chronic pain conditions affecting walking capacity, a longer double support phase has been described as a self-protection against pain or to maintain dynamic balance (Cimolin et al., 2011; Demirel et al., 2020; Li et al., 2022). Other gait parameters such as angles related to foot position (e.g., strike angle and lift-off angle) can provide information on lower limb joints kinematics, as well as balance, lower limbs muscle strength and the overall loading to reduce pain (Chopra & Crevoisier, 2019; d'Andrea et al., 2023; Lanzi et al., 2021; Li et al., 2021). Finally, foot clearance parameters can inform clinicians about the risk of falls in older adults (Al Bochi et al., 2021; Nagano, 2022). These walking parameters are potentially useful to clinicians when evaluating the effectiveness of rehabilitation treatment strategies for patients with LSS causing NC.

Since LSS causing NC typically affects older adults, and because the aging process is known to be associated with changes in gait parameters such as a decrease of walking speed, stride length, cadence and an increase of double-support time (Crawford et al., 2018; Herssens et al., 2018; Lee et al., 2017), it is important to identify specific LSS gait changes. Therefore, the aim of the present study was to compare gait parameters between patients with LSS causing NC and pain-free older adults. We hypothesized that cycle duration, stance phase, foot-flat subphase and double support phase would be higher in patients with LSS causing NC than in pain-free older adults. We also hypothesized that cadence, stride length, speed, loading and pushing subphases duration, swing phase duration, peak angular velocity, heel-strike pitch angle, toe-off pitch angle, maximum heel clearance and minimal toe clearance would be lower in patients with LSS causing NC than in pain-free older adults.

METHODS

Study design

This cross-sectional study was conducted at the Université du Québec à Trois-Rivières (UQTR) and at the Centre Intégré Universitaire de Santé et de Services Sociaux de la Mauricie et du Centre-du-Québec (CIUSSS MCQ) between November 2019 and January 2024. This study received ethical approval from the UQTR Institutional Review Board (CER-20-268-07.14) and the CIUSSS MCQ Research Ethics Committee (CÉRM-2019-005-00). All methods were carried out following the relevant guidelines and regulations, and all participants provided informed written consent prior to their participation in the study. The study has been registered on ClinicalTrials.gov (NCT04795284) on March 3rd 2021.

Participants

One hundred and thirty-five (135) participants aged at least 50 (35 patients with LSS causing NC and 100 pain-free adults) were recruited for this study. Patients with LSS causing NC were recruited through the CIUSSS MCQ, in collaboration with the neurosurgery team, or through the UQTR chiropractic outpatient clinic, while pain-free older adults were recruited via social media platforms (e.g., Facebook). For patients with LSS causing NC, inclusion criteria were as follow: having a confirmed diagnosis of symptomatic central LSS causing NC at one or multiple levels, having leg pain dominance, being able to walk with or without walking aids. For pain-free older adults, the inclusion criterion was the absence of pain during walking. Exclusion criteria for participants in both groups were as follow: uncontrolled diabetes, recent (< 3 months) lumbar or lower limb surgery, previous knee or hip joint replacement, neurological diseases affecting walking capacity (such as Parkinson's disease), vascular intermittent claudication, and impaired cognitive capacity.

Data collection

Sociodemographic data

Data collection began with a brief history that included the following sociodemographic information: age, height, weight, and sex.

Clinical outcome measures

Patients with LSS causing NC were questioned about their current back and leg pain intensities. Back and leg pain intensities were assessed using a 10 cm visual analog scale (VAS) with a score of 3.4 or less indicating mild pain, 3.5 to 7.4 moderate pain, and 7.5 or more severe pain (Boonstra et al., 2014). Participants in both groups completed a series of questionnaires. The level of physical activity was assessed using the reliable and validated French adaptation of the short version of the International Physical Activity Questionnaire (IPAQ) (CRAIG et al., 2003). The 9-item questionnaire provides information related to physical activity habits intensity in the past week. Physical activity is divided into four domains (vigorous-intensity activity, moderate-intensity activity, walking, and sitting) and the questionnaire allows a classification of three physical activity levels (low activity, moderate activity or high activity) based on the number of days practicing activities and the activity intensity (Lee et al., 2011). Health-related quality of life was assessed using the French adaptation of the EuroQol-5D questionnaire (EQ-5D) (Perneger et al., 2010). The descriptive part of the questionnaire provides information regarding the general health status along five dimensions: mobility, self-care, usual activities, pain or discomfort, and anxiety or depression. For each dimension, participants were invited to indicate one of three levels of severity using a 3-point Likert scale (1 = no problem, 2 = moderate problems and 3 = severe problems). Participants also rated their overall health status by hash-marking a 20 cm vertical VAS on which 0 represented the worst imaginable health state and 100, the best imaginable one (Perneger et al., 2010; Rabin & de Charro, 2001). Patients with LSS causing NC completed the French-Canadian adaptation of the Swiss Spinal Stenosis Questionnaire (FC-SSSQ). This questionnaire is a validated specific tool used to assess pain, function and satisfaction with care commonly used in patients with LSS causing NC (A. A. Marchand et al., 2019). Because no patients had undergone surgery, the satisfaction with care subscale was removed. The pain subscale includes seven questions of which six are scored using a five-point Likert scale and the seventh question is scored using 1, 3 or 5 points. The function subscale includes five questions, which are scored using a four-point Likert scale. For each subscale, a higher score indicates greater disability. The total score of the FC-SSSQ without the satisfaction subscale was 55 points.

Walking task

All participants performed a walking task that consisted of walking on a 30-meter round trip at a self-selected pace. The walking task was performed twice, and each trial was followed by a 2-minute rest period in a seated position to allow participants to recover. The first trial was considered the familiarization phase of the task. During the walking task, gait parameters were measured using wearable inertial measurement units (IMUs) from Physilog®6 (Gait Up, Lausanne, Switzerland) attached to the top of each participant's shoes using elastic straps. Both inertial sensors were synchronized and manually activated and deactivated before and after each walking trial. Each inertial sensor contains a three-dimensional (3D) accelerometer (±4g), a 3D gyroscope (±1000˚/s) with a sampling frequency of up to 512Hz, a magnetic field sensor (±50mT; 256Hz), and a barometer (0-64Hz). Both left and right foot information was collected during the walking task. The use of a walking aid was permitted for patients with LSS causing NC, and they were also allowed to stop walking at any moment if needed because of pain.

Gait parameters – Data analysis

Data from the synchronized Physilog®6 sensors were analyzed with Gait Analysis Software (v. 5.2, Gait Up Lausanne, Switzerland). Gait characteristics were classified into general (cycle duration, cadence, stride length, speed), temporal (stance, including stance subphases such as loading, foot-flat and pushing ratio, swing and double support), spatial (peak angular velocity, heel-strike pitch angle, toe-off pitch angle), and clearance (maximum heel clearance, minimal toe clearance) categories. The definition of each gait parameter is provided in Table 4.1. The first and last two gait cycles were excluded, as recommended, to focus on steady-state data. Values related to turns were discarded for straight-line analysis. For data analyses, only the dominant leg of pain-free adults (the leg they typically use for kicking a ball) and the most painful or disabled leg of patients with LSS causing NC were used, except for characteristics requiring information from both feet, such as cycle duration, cadence, and walking phases.

Table 4.1 - Definition of gait parameters

Gait parameters	Definition
General gait parameters	
Cycle duration (s)	Time between two consecutive heels touching the ground for a same foot.
Cadence (steps/min)	Number of gait cycles in a minute.
Stride length (m)	The distance between heels of two consecutive footprints for the same foot.
Speed (m/s)	Average forward walking speed.
Temporal gait parameters	
Stance phase (%)	The percentage of time during which the foot is touching the ground during a gait cycle.
Loading (%)	The percentage of time during the stance phase between the heel strike and the foot being flat on the ground.
Foot-flat (%)	The percentage of time during the stance phase when the foot is flat on the ground.
Pushing (%)	The percentage of time during the stance phase between the foot being flat on the ground and the toe leaving the ground.
Swing phase (%)	The percentage of time during which the foot is not touching the ground during a gait cycle.
Double support (%)	The percentage of time during which both feet are touching the ground during a gait cycle.
Spatial gait parameters	
Peak angular velocity (°/s)	The maximal angular velocity of the foot during the swing, between maximum heel clearance and minimum toe clearance.
Heel-strike pitch angle (°)	The angle between the foot and the ground during heel strike.
Toe-off pitch angle (°)	The angle between the foot at the end of the push phase and the ground.
Clearance parameters	
maxHC (m)	Maximal height above the ground reached by the heel during each gait cycle.
minTC (m)	Minimum height of the toes during swing phase.

Statistical analysis

The normality of data distribution was assessed using the Kolmogorov-Smirnov test and by visually inspecting the corresponding histograms for each dependent variable. Due to the non-normal distribution of the data, the Box-Cox transformation was applied to the dependent variables to achieve normality and ensure equal group variances (Marimuthu et al., 2022). Means and standard deviations were reported for continuous variables, while proportions were reported for dichotomous variables. Group comparisons for sociodemographic data, clinical outcome measures and gait parameters were conducted using independent t-tests or chi-square tests. If there was a significant difference between groups for gait parameters, analyses of covariances

(ANCOVAs) were conducted. Given the different group sizes, all ANCOVA assumptions have been verified and validated to ensure the analysis is appropriate. Covariables included in the ANCOVAs analyses were sex, age, height, and weight. These sociodemographic data are factors known to influence gait parameters (Hollman et al., 2011; Rowe et al., 2021; Samson et al., 2001; Wolff et al., 2023). Statistical analyses were performed using IBM SPSS Statistics version 29 (Armonk, NY: IBM Corp.), with a significance level set at $p < 0.05$.

RESULTS

Between-group comparisons for sociodemographic data and clinical outcome measures

Results from between-group comparisons for sociodemographic data and clinical outcome measures are presented in Table 4.2. The results showed that groups differed significantly for sex ($p < 0.001$). Additionally, patients with LSS causing NC were older, taller, and heavier than the pain-free older adults (ps < 0.001). As for the use of walking aids, seven patients with LSS causing NC reported using one occasionally. No participants used the walking aid during the walking task. Clinical outcome measures indicate that pain-free older adults reported higher levels of physical activity and better quality of life than patients with LSS causing NC (ps < 0.001). The number of participants from each group for each level of severity according to all quality of life domains is presented in Table 4.3.

Table 4.2 - Sociodemographic characteristics and clinical outcome measures for each group of participants

	Patients with LSS causing NC (n = 35) (Mean ± SD)	**Pain-free older adults** (n = 100) (Mean ± SD)	**t-test *p-value***	**Chi-square *p-value***
Sociodemographic data				
Sex (F : M)	11 : 24	64 : 36	-	< 0.001
Age (years)	67.86 ± 8.38	63.84 ± 8.11	0.014	-
Height (m)	1.72 ± 0.12	1.66 ± 0.10	0.003	-
Weight (kg)	91.04 ± 21.22	71.34 ± 14.19	< 0.001	-
BMI (kg/m^2)	30.71 ± 6.12	25.99 ± 4.65	< 0.001	-
Back pain VAS (0 – 10 cm)	2.29 ± 2.51	-	-	-
Leg pain VAS (0 – 10 cm)	2.69 ± 2.81	-	-	-
Using a walking aid				
Yes (n, %)	7 (20.00%)	0 (0.00%)	-	< 0.001
No (n, %)	28 (80.00%)	100 (100.00%)	-	
Clinical outcome measures				
IPAQ			-	
Low level of PA (n, %)	23 (65.71%)	11 (11.00%)		< 0.001
Moderate level of PA (n, %)	12 (34.29%)	44 (44.00%)		
High level of PA (n, %)	0 (0.00%)	45 (45.00%)		
EQ-5D VAS (/100)	68.37 ± 19.69	90.53 ± 8.62	< 0.001	-
FC-SSSQ (/55)	34.49 ± 9.12	-	-	-

LSS = Lumbar Spinal Stenosis, NC= Neurogenic Claudication, SD = Standard Deviation, F = Female, M = Male, BMI = Body Mass Index, VAS = Visual Analog Scale, IPAQ = International Physical Activity Questionnaire and FC-SSSQ = French-Canadian adaptation of the Swiss Spinal Stenosis Questionnaire

Table 4.3 - Number of participants in each group for each level of severity according to all quality of life domains

Domains	Patients with LSS causing NC (n = 35) (Mean ± SD)			Pain-free older adults (n = 100) (Mean ± SD)			Chi-square *p-value*
	1	2	3	1	2	3	
Mobility	12	23	0	100	0	0	< 0.001
Self-care	31	4	0	100	0	0	< 0.001
Usual activities	11	23	1	100	0	0	< 0.001
Pain or discomfort	3	24	8	99	1	0	< 0.001
Anxiety or depression	23	11	1	88	11	1	< 0.001

Level: 1 = no problem, 2 = some problems, 3 = severe problems

Between-group comparisons for gait parameters

All between-group comparisons for gait parameters are presented in Table 4.4. There were significant between group differences for all gait parameters (*ps* ≤ 0.016), except for the maximal heel clearance (*p* = 0.348). More specifically, cycle duration was longer, cadence lower, stride length shorter, and speed lower in patients with LSS causing NC than in pain-free older adults (*ps* < 0.001). For temporal parameters, results showed that the stance phase and double support were longer, and the swing phase shorter in patients with LSS causing NC than in pain-free older adults (*ps* < 0.001). As for the stance subphases, the loading and pushing ratios were shorter, while the foot-flat ratio was longer in patients with LSS causing NC compared to pain-free older adults (*ps*= [< 0.001 – 0.002]). For spatial parameters, significantly lower peak angular velocity, heel-strike pitch angle and toe-off pitch angle were observed in patients with LSS causing NC (*ps* < 0.001). Due to group differences in sociodemographic data such as sex, age, height, and weight, ANCOVAs were conducted for all gait parameters, except maximal heel clearance. Results of the ANCOVAs showed that, after adjusting for sex, age, height, and weight, the differences between groups remained significant for all gait parameters (*ps*= [< 0.001 - 0.012]) except minimal toe clearance (*p* = 0.404). The ANCOVAs details are presented in Appendix 1 (*Annexe H de la thèse*).

Table 4.4 - Mean biomechanical gait parameters for each group of participants

Gait parameters	Patients with LSS causing NC (n = 35) (Mean ± SD)	Pain-free older adults (n = 100) (Mean ± SD)	T-test *p-value*	Confidence Interval (95%)
General parameters				
Cycle duration (s)	1.28 ± 0.33	1.04 ± 0.16	< 0.001	0.160 – 0.328
Cadence (steps/min)	99.81 ± 16.32	117.97 ± 9.64	< 0.001	- 22.70 – -13.60
Stride length (m)	1.06 ± 0.21	1.38 ± 0.14	< 0.001	- 0.38 – -0.25
Speed (m/s)	0.92 ± 0.27	1.37 ± 0.18	< 0.001	-0.53 – - 0.37
Temporal parameters				
Stance phase (%)	63.52 ± 3.61	61.03 ± 1.96	< 0.001	1.52 – 3.46
Loading (%)	10.51 ± 3.63	12.50 ± 2.54	0.002	-3.10 – - 0.88
Foot-flat (%)	63.10 ± 8.28	51.87 ± 5.79	< 0.001	8.69 – 13.75
Pushing (%)	26.39 ± 5.78	35.63 ± 5.10	< 0.001	-11.29 – -7.18
Swing phase (%)	36.48 ± 3.61	38.97 ± 1.96	< 0.001	-3.46 – -1.52
Double support (%)	26.98 ± 6.24	21.88 ± 3.47	< 0.001	3.41 – 6.79
Spatial parameters				
Peak angular velocity (°/s)	315.63 ± 73.11	421.34 ± 61.19	< 0.001	-130.74 – -80.67
Heel-strike pitch angle (°)	20.51 ± 6.04	26.57 ± 4.95	< 0.001	-8.09 – - 4.01
Toe-off pitch angle (°)	-57.74 ± 11.10	-72.73 ± 6.49	<0.001	11.92 – 18.08
Clearance parameters				
maxHC (m)	0.288 ± 0.101	0.304 ± 0.082	0.348	-0.561 – 0.016
minTC (m)	0.033 ± 0.008	0.029 ± 0.009	0.016	-0.000 – 0.010

LSS = Lumbar Spinal Stenosis, NC = Neurogenic Claudication, ANCOVA = Analysis of Covariance, SD = Standard Deviation, maxHC = maximal heel clearance, minTC = maximal toe clearance

DISCUSSION

The objective of the present study was to compare gait parameters between patients with LSS causing NC and pain-free older adults. The study investigated general, temporal, spatial and clearance gait parameters. Our results showed that, after adjustment for covariables (sex, age, height, and weight), most gait parameters significantly differed between patients with LSS causing NC and pain-free older adults. These differences suggest that compensatory strategies are adopted by patients with LSS causing NC during walking. In our study, patients with LSS causing NC showed a lower quality of life and physical level than pain-free older adults, which is consistent with current scientific knowledge on LSS causing NC (Özdemir et al., 2015; Sobottke et al., 2017).

Regarding general gait parameters, our results are consistent with what has been previously reported for patients with LSS causing NC (Li et al., 2021; Wang et al., 2022). Decreased walking speed, stride length, cadence and increased gait cycle duration are believed to represent a strategy used to decrease pain and enhance stability during walking in patients with chronic pain (Bejek et al., 2006; Constantinou et al., 2014; Wang et al., 2024). In LSS causing NC, these modifications seem congruent with the presence of NC symptoms that are exacerbated by the lumbar extension occurring during walking (Li et al., 2021; Perring et al., 2020). Indeed, patients with LSS and NC already have a decreased central canal size, which worsens when they adopt a standing position (Katz et al., 2022), leading to lumbar extension and pelvic tilt (Levine et al., 2007). To alleviate symptoms patients with LSS and NC modify walking speed and stride length since lumbar extension decreases at lower walking speed and shorter stride length (Levine et al., 2007). Previously, Igawa and colleagues suggested, in a study examining hip kinematics, that patients with LSS and NC might use such a strategy to reduce activation of the psoas major muscle, thereby limiting lumbar extension during walking (Igawa et al., 2018). Further studies are needed to understand the clinical potential of this strategy in alleviating NC-related pain during walking, which could lead to more effective non-invasive treatments targeting improved mobility and quality of life.

Changes in general gait parameters are typically accompanied by changes in gait temporal and spatial parameters. In our study, there were significant differences between patients with LSS causing NC and pain-free older adults for all temporal and spatial parameters. These differences have also been shown in previous studies including patients with LSS, knee or ankle osteoarthritis (Chopra & Crevoisier, 2019; Khazzam et al., 2006; Li et al., 2022; Li et al., 2021). The lower peak angular velocity, in heel-strike angle and toe-off pitch angle observed in our study could indicate modifications in lower limb joint movement, such as a decrease in hip or knee range of motion. By reducing the range of motion voluntary during walking, patients with LSS causing NC can potentially reduce the loading of the painful leg and perceived pain (Bejek et al., 2006; Khazzam et al., 2006). Moreover, the between-group differences observed in the different walking phases suggest that strategies to reduce loading of the painful leg and increase stability were used by patients with LSS causing NC in our study. By decreasing their gait speed, patients with LSS causing NC prolonged their stand phase duration. This prolonged stance phase reduces the duration of the loading and pushing subphases, which are related to heel strike and toe-off pitch angles, allowing patients to reduce the overall load and its impact on the painful lower limb (Chopra & Crevoisier, 2019). In addition, the decrease of swing phase duration and the increase of double support phase duration allow patients to have a larger base of support, improving stability while walking (Li et al., 2021). Increasing the double support duration also allows for a better load distribution. The extended time spent with both feet on the ground also offers an opportunity to correct gait changes, ultimately enhancing gait control and overall mobility (Williams & Martin, 2019). Overall, our results suggest that patients with LSS causing NC exhibit changes in gait that are mostly driven by a strategy to reduce pain and improve stability.

Our study revealed that the gait clearance parameters of patients with LSS causing NC did not differ from those of pain-free older adults, which was contrary to our hypothesis. The minimal toe clearance parameter has previously been identified as an important factor for the risk of fall in older adults (Chiba et al., 2005). A recent scoping review reported that aging does not significantly affect the average minimal toe clearance parameter, but does increase its variability among older adults (Al Bochi et al., 2021). Another study suggested that greater variability in minimal toe clearance during walking indicates a higher risk of falls, as the foot has a greater chance to touch the ground during the swing phase (Mills et al., 2008). As symptoms related to LSS with NC typically worsen with walking time, the ability of patients with LSS causing NC to lift their feet may decrease with increasing walking time, leading to a reduction in minimal toe clearance during longer walking tests. Therefore, further studies assessing walking gait parameters during prolonged walking are needed to confirm this hypothesis.

Strengths and limitations

To our knowledge, this is the first study comparing spatial and clearance gait parameters between patients with LSS causing NC and pain-free older adults. Another strength of this study is the use of IMUs for the detection of gait changes attributable to LSS causing NC condition, which allows participants to walk without restrictions throughout the walking task. Additionally, the IMUs used can be applied in restricted environments, such as clinical settings. They also provide relevant clinical information for determining the progression of the condition in patients and the effectiveness of treatments on gait parameters. This study is, however, not without limitations. Although the patients with LSS causing NC who were included in our study reported LSS-related disability, their mean back and leg pain prior to the walking task were considered mild. Assessments of gait changes according to back and leg pain intensity level (e.g., mild, moderate and severe) are needed to better understand the impact of pain on gait patterns of patients with LSS causing NC. The fact that pain intensity increases with walking time further supports the need for studies assessing walking gait parameters during prolonged walking.

CONCLUSION

The results of the present study showed that gait parameters except for clearance parameters differed between patients with LSS causing NC and pain-free older adults. These results suggest that patients with degenerative LSS causing NC had altered gait parameters. Further studies assessing gait parameters during longer walking tasks in relation to different levels of pain are needed to better understand how gait parameters are impacted by symptoms onset in LSS causing NC. It would also be relevant to assess the association between gait changes and walking capacity.

DECLARATIONS

Ethics approval and consent to participate: This study received ethical approval from the UQTR Institutional Review Board (CER-20-268-07.14) and the CIUSSS MCQ Research Ethics Committee (CÉRM-2019-005-00). All methods were carried out following the relevant guidelines and regulations, and all participants provided informed written consent prior to their participation in the study.

Consent for publication: Not applicable

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Authors' Contributions: Research area and study design: MH, CT, CEC, AAM, MD; recruitment: MH, JO and CEC; data acquisition: MH and CT; statistical analysis: MH, AAM, MD; supervision and mentorship: AAM and MD. Manuscript writing: MH, AAM, JO, CT and CEC. MD takes responsibility that this study has been reported transparently and honestly. All authors have read and approved the manuscript.

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Chapitre 5 – Article 4, Effectiveness of a 6-week specific rehabilitation program combining education and exercises on walking capacity in patients with lumbar spinal stenosis with neurogenic claudication: a randomized controlled clinical trial protocol

Ce chapitre inclut le quatrième article de cette thèse qui a été publié dans la revue « *Trials* » en 2021.

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Résumé

Contexte : La sténose spinale lombaire (SSL) avec claudication neurogène (CN) est l'une des principales causes d'incapacité et est associée à une diminution de la capacité de marche. Cette diminution de la capacité de marche est connue pour avoir un impact négatif sur les facteurs physiques et psychologiques des patients. Les plus récentes lignes directrices en matière de prise en charge recommandent l'utilisation de traitements conservateurs tels que les exercices avant d'envisager la chirurgie. Malheureusement, les ressources dédiées à la prise en charge conservatrice des patients atteints de SSL avec CN sont rares. Il est donc important de développer des programmes de réadaptation accessibles et spécifiques, visant à améliorer l'autogestion des patients, en particulier en ce qui concerne la capacité de marche. Cette étude a pour objectif d'évaluer l'efficacité d'un programme spécifique de réadaptation de 6 semaines combinant de l'éducation et des exercices sur la capacité de marche des patients ayant une LSS avec CN.

Méthodologie : Il s'agit d'un essai clinique prospectif randomisé en groupes parallèles. Soixante-six patients atteints de LSS causant NC seront recrutés dans des cliniques identifiées et par des annonces locales. Le groupe d'intervention recevra une éducation standardisée et des exercices spécifiques, tandis que le groupe contrôle ne recevra que l'éducation standardisée, le tout pendant 6 semaines. Le projet compte 5 évaluations (évaluation initiale, semaine 2, 4, 6 et 12). La mesure de résultat primaire sera la capacité de marche mesurée par le Self-Paced Walking Test et les mesures de résultats secondaires incluront l'intensité de la douleur au dos et des jambes, l'incapacité liée à la SSL, le sentiment d'auto-efficacité, le niveau d'activité physique, l'anxiété, la dépression, les caractéristiques du patron de marche, l'équilibre, et le changement global perçu.

Discussion : Cette étude évaluera l'efficacité d'un programme spécifique de réadaptation d'une durée de 6 semaines combinant éducation et exercices sur la capacité de marche des patients ayant un diagnostic de SSL avec CN. En mesurant les caractéristiques objectives du patron de marche, l'étude fournira également de nouvelles informations sur l'impact de la CN sur le patron de marche, ce qui peut aider à améliorer l'évaluation et la gestion de la SSL.

Enregistrement de l'essai : Ce protocole d'étude a été enregistré sur ClinicalTrials.gov (NCT05513326) le 22 août 2022 (https://clinicaltrials.gov/ct2/show/NCT05513326).

Mots-clés : *Claudication neurogène, capacité de marche, exercices, éducation, sténose spinale, essai contrôlé randomisé.*

Abstract

Background: Lumbar spinal stenosis (LSS) causing neurogenic claudication (NC) is a leading cause of disability which is intimately related to a decrease in walking capacity. Walking limitation has negative physical and mental impacts on patients. Recent guidelines recommend the use of conservative treatment options such as exercises before considering surgery. Unfortunately, dedicated health care resources for the conservative management of patients with LSS causing NC are uncommon. Thus, it is important to develop accessible and specific rehabilitation programs aimed at improving patients' self-management, especially with regard to walking capacity. The aim of this study is to evaluate the effectiveness of a 6-week specific rehabilitation program combining education and exercises on walking capacity in patients with LSS causing NC.

Methods/Design: This is a prospective randomized controlled parallel-group clinical trial. Sixty-six patients with LSS causing NC will be recruited from identified clinics and local advertisements. The intervention group will receive standardized education and specific exercises while the control group will only receive standardized education. The program in both groups will last for 6 weeks with 5 evaluation timepoints (baseline, week 2, week 4, week 6 and week 12). The primary outcomes will be walking capacity measured with the Self-Paced Walking Test and the secondary outcomes will be back and leg pain intensity, LSS-related disability, self-efficacy, level of physical activity, anxiety, depression, gait pattern characteristics, balance, and global perceived change.

Discussion: This study will assess the effectiveness of a 6-week specific rehabilitation program combining education and exercises on walking capacity in patients with LSS causing NC. By measuring objective gait pattern characteristics, the study will also provide new information about the impact of NC on gait pattern that could eventually improve the evaluation and the management of LSS.

Trial registration: This study protocol has been registered on ClinicalTrials.gov (NCT05513326) on August 22th, 2022 (https://clinicaltrials.gov/ct2/show/NCT05513326).

Key Words: Neurogenic claudication, walking capacity, exercises, education, spinal stenosis, randomized controlled trial

BACKGROUND

Neurogenic claudication (NC) is a clinical syndrome recognized as the hallmark of symptomatic lumbar spinal stenosis (LSS)(Lurie & Tomkins-Lane, 2016), a degenerative musculoskeletal condition caused by age-related changes in the lower spine and defined as the narrowing of the spinal canal or intervertebral foramina (Hartvigsen et al., 2018; Kalichman et al., 2009). Neurogenic claudication is characterized by bilateral or unilateral buttock, thigh or leg pain and discomfort such as numbness, tingling and weakness (Genevay & Atlas, 2010; Katz & Harris, 2008; Knezevic et al., 2021; Porter, 1996). Theses symptoms are exacerbated by prolonged standing or walking, and they are temporarily relieved by sitting and bending forward (Knezevic et al., 2021; Lurie & Tomkins-Lane, 2016). Because of its symptomatology, especially during daily activities that require walking, NC represents one of the leading causes of pain and disability in the elderly (Fanuele et al., 2000).

Over the past years, decreased walking capacity in patients with LSS causing NC, measured in time or distance, has been well documented using objective walking tests (treadmill and self-paced walking tests)(Tomkins-Lane et al., 2012; Tomkins et al., 2009). Moreover, a recent systematic scoping review reported that walking capacity was negatively associated with pain outcomes and disability (Houle et al., 2021). In addition, greater disability scores were negatively associated with walking speed and stride length, two important gait pattern characteristics of LSS (Houle et al., 2021). Patients consider walking capacity and pain to be the most bothersome consequences of NC. They also report that decreased walking capacity is responsible for disrupting their daily life activities (e.g. walking, social activities, household activities, sleeping and lifting) (Ammendolia et al., 2017). Furthermore, the decline in walking capacity due to NC is reflected in an increase of inactivity. Adoption of such a sedentary lifestyle contributes to a decline in quality of life especially with respect to physical status (Evenson et al., 2012; Justin Norden et al., 2017). Previous studies showed that patients with LSS causing NC are less active than the general population over the age of 60 and individuals with hip or knee osteoarthritis, with approximately 82% of their time spent in sedentary behaviour (Evenson et al., 2012; J. Norden et al., 2017; Winter et al., 2010).

Walking limitations related to LSS causing NC do not only affect patients physically. When asked about their wellbeing and psychological state, most patients report that they feel sad, discouraged and/or anxious and that they lost interest in doing certain activities because of their condition (Ammendolia et al., 2017). However, there are many different ways to assess psychological factors including anxiety and depression in both clinical and research settings. Due to the lack of standardization regarding the assessment of psychological factors, the association between walking capacity and psychological factors in patients with LSS causing NC remains uncertain (Houle et al., 2021).

Walking limitations and pain related to NC are central the management of LSS (Ammendolia et al., 2017; Genevay et al., 2018; Lurie & Tomkins-Lane, 2016). Several therapeutic options are available for patients with LSS causing NC including conservative approaches and surgical options. According to recent practice guidelines, surgical options should only be considered when less invasive treatments such as manual therapy, physiotherapy, exercises and injections have failed to improve symptoms (Bussières et al., 2021). Having additional resources such as exercises and education in patients' health care trajectories could help them to at least maintain their functional capacities. Furthermore, underlying medical conditions may limit surgical options in this population. To date, dedicated programs providing active treatments such as exercises to patients with LSS causing NC are scarce. Further, the often protracted delay between diagnosis and eventual surgery may be an opportunity to help patients improve both their pre- and post-surgical functional capacity.

Neurogenic claudication related to LSS can be experienced differently over time and between patients, especially regarding leg pain intensity, time to first symptoms when walking, and total walking time. Knowing that there are currently no specific resources to guide active treatment such as exercises for patients with LSS, identifying and developing specific and flexible rehabilitation programs to help patients to maintain or improve their walking capacity would address an important knowledge gap. Such a program would offer an additional access to health care during patients' care trajectories in addition to offering a chance for patients to self-manage their condition over time. This new opportunity should help them strengthen their self-efficacy during daily living.

Bove and colleagues reported that patients value individual sessions focused on their specific impairments and limitations as well as specific tips on self-management strategies (Bove et al., 2018). In the last few years, RCTs involving patients with LSS causing NC were designed to include education as part of the intervention (Ammendolia et al., 2018; Comer et al., 2013b; Delitto et al., 2015; Hammerich et al., 2019). However, the authors did not describe in detail the content of the education program (i.e., daily living tips to limit pain, information regarding walking and sleeping) nor how it was delivered during the study (e.g. frequency, duration, delivery methods such as individual session or information flyers) making the replication of those studies difficult.

The aim of the proposed protocol is to evaluate the effectiveness of a 6-week specific rehabilitation program combining education and exercises on walking capacity in patients with LSS causing NC. It is hypothesized that a 6-week specific rehabilitation program combining education and exercises will have a superior effect on walking capacity than education alone.

METHODS/DESIGN

Study design

The proposed study is a prospective randomized controlled parallel-group clinical trial (RCT) that aims to evaluate the superior effect of a 6-week specific rehabilitation program combining exercises and education compared to education alone (see figure 5.1). In this RCT, participants with LSS causing NC will be allocated to either the intervention group (LSS group) or the control group. All proposed methods are in accordance with the CONSORT statement which provides relevant guidelines and regulations for RCTs (Schulz et al., 2010). The study protocol is written in conformity with the SPIRIT (Standard Protocol Items: Recommendations for Interventional Trials) statement (Chan et al., 2013) and has been registered on ClinicalTrials.gov (NCT05513326) on August 22th, 2022.

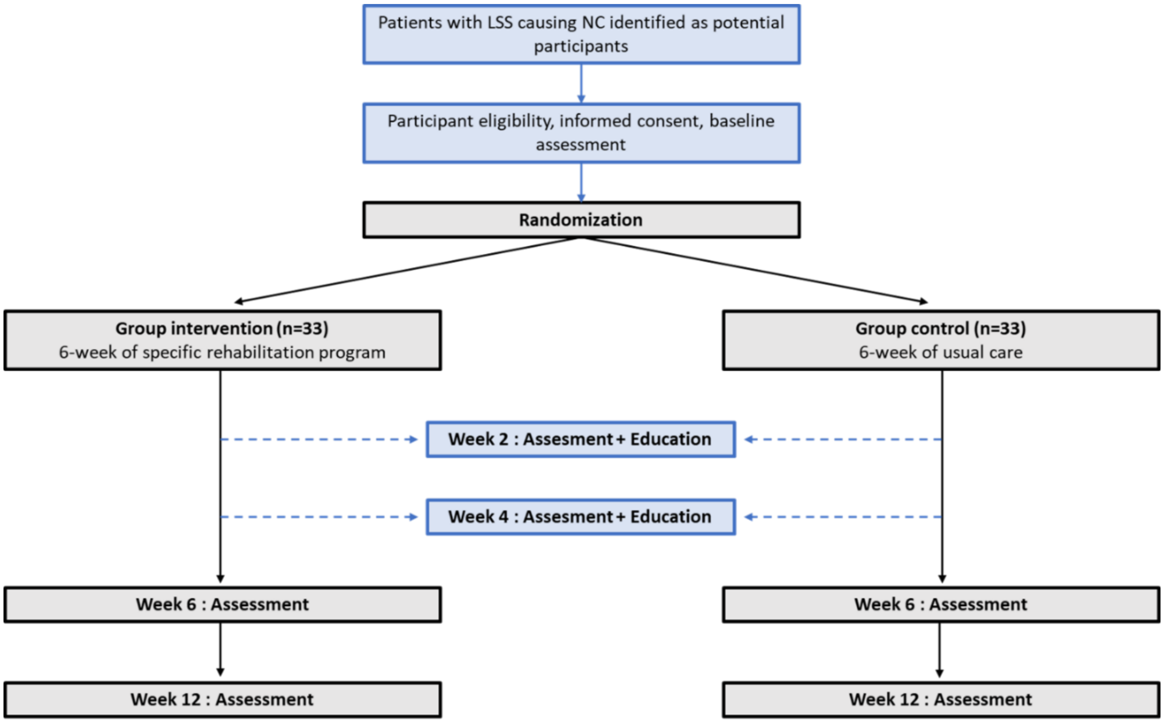

Figure 5.1 - Study timeline

LSS = lumbar spinal stenosis, NC = neurogenic claudication

Recruitment

Potential participants will be identified by neurosurgeons and chiropractors from collaborating clinics during regular scheduled appointments or by advertising in the local newspapers or via social media. Both recruitment strategies (pamphlet given by clinicians or local publicity) will include information regarding the study objectives, patient implication, and contact information of the trial coordinator. If interested, participants will be screened for eligibility criteria over the phone and then an assessment date will be set. Collaborating clinics are located in Trois-Rivières (Québec, Canada) and refer to the chiropractic university teaching clinic and to the regional hospital neurosurgery outpatient clinic.

Eligibility criteria

To be eligible, participants must meet the following inclusion criteria: (1) being at least 50 years old, (2) having a degenerative central LSS alone or in combination with other LSS types (e.g.

foraminal, lateral recess) and/or a spondylolisthesis affecting one or multiple vertebral levels, confirmed by clinical history, physical examination and proper imaging (MRI and/or CT-scan), (3) having NC associated with LSS, (4) with a duration of signs and symptoms of at least 3 months, (5) being able to walk at least 20 meters without walking aid, but not being able to walk continuously for 30 minutes, (6) being willing to attend 3 intervention sessions per week over a period of 6 weeks (7) being able to speak and understand French and (8) being able to provide informed written consent. Participants with congenital LSS, traumatic and pathological causes of LSS, symptomatic osteoarthritis (hip or knee) causing limited walking capacity, a neurological disease affecting walking capacity such as Parkinson, uncontrolled diabetes, heart failure, intermittent claudication of vascular origin, impaired cognitive capacity and history of back or lower extremities surgery in the past 3 months will be excluded.

Ethical considerations

This study will be conducted according to the Helsinki Declaration. The proposed study protocol received approval from the CIUSSS MCQ research ethics committee (CÉR-2023-649) and from the Human Research Ethics Board of UQTR which recognised the ethics approval first received from the CIUSSS MCQ. Participants will be informed that they can withdraw at any moment during the study without having to provide an explanation and without negative consequences on their healthcare trajectory. Participants will be asked for permission from the research team to share relevant data with people from the Universities taking part in the research or from regulatory authorities, when relevant. Also, it is important to note that if a participant is finally considered by a neurosurgeon for surgery, the proposed protocol will not interfere or delay the surgery. Participants randomized to the control group (education alone) will be offered the specific rehabilitation program after the completion of the study. Written informed consent will be obtained by all participants before completing the baseline assessment. This study does not involve collecting biological specimens for storage.

Randomization

All included participants will be randomized into one of the two groups (intervention or control) using a minimization method (allocation ratio of 1:1) to ensure that both groups will be balanced with respect to predetermined criteria. These minimization criteria have been identified based on factors known to have a negative influence on walking capacity and include smoking, diabetes, chronic obstructive pulmonary disease and stroke. All criteria will have the same weight in the minimization process. Participants will be randomized using a computer-generated list of random numbers which will be placed into sealed and opaque envelopes numbered by an independent research assistant that is not involved in the selection, intervention or assessment of participants. Each envelope will be opened in front of the participants at the end of the baseline assessment by another independent research assistant.

Blinding

The researchers performing data collection as well as those performing statistical analyses will be blinded to group allocation.

Interventions

Intervention Group

Participants allocated to the intervention group will receive a 6-week specific rehabilitation program which includes training and education sessions. The one-on-one training sessions will be composed of specific exercises to be performed 3 times per week under the supervision of a certified kinesiologist. Of the three training sessions, one will take place at UQTR's outpatient clinic while the other two will take place online using a telecommunication platform (e.g. Zoom or Google Duo, depending on the participant's preference) allowing for a remote supervision of the training by the certified kinesiologist. Instructions regarding the selected telecommunication platform will be provided to participants. Education will take place at week 2 and week 4 with the researcher responsible of assessments. Presences to exercises and education sessions will be monitored by the responsible research team member (CT for exercises and MH for education).

Exercises

Each training session will last 30 minutes with a focus on lower limb muscle strengthening as well as balance. Sessions will start with 5 minutes of activation (walking on a treadmill or cycling). Then, participants will be asked to complete 5 exercises targeting lower limb strengthening (time: 18 minutes) followed by 2 exercises designed to improve balance and 3 stretching exercises for the lower limb (time: 7 minutes). Levels of difficulty for each exercise will vary according to the patient's capacity to ensure that each exercise is appropriate and safe while allowing a progression over time.

Education

Education will consist of two one-on-one sessions (during week 2 and week 4 assessments) during which participants will receive information directly related to LSS and NC using pre-recorded standardized videos developed for the study. This information consists of explanations of the pathophysiology of LSS and NC as well as expected natural history, usual symptoms, pain management strategies for daily living (body positioning when walking and when sleeping) and physical activity recommendations. Illustrations and videos will be used to enhance participants understanding and to ensure a standardized delivery of education. Participants will also be invited to ask questions. Each session will last for 20 minutes.

Control Group

The participants in the control group will only receive the education sessions at week 2 and at week 4.

Participant trajectories

Regardless of group allocation all participants will continue to follow their usual care routine. Usual care can include general advice for daily living, advice to stay active, oral medication to control pain, inflammation, or mood as well as referral for spinal injection. Their treatments will be monitored throughout the study duration.

Data collection

Participants will be evaluated five times during the study (baseline, week 2, week 4, week 6 and week 12). Each assessment will include both patient-reported outcome measures (PROMs) and objective physical measures. All assessments will be conducted at the UQTR biomechanics laboratory. The data collection process is synthesized in table 5.1. All participants will be called for a reminder before each assessment.

During the baseline assessment, participants will first complete a series of questionnaires and undergo a standardized physical examination. The questionnaires will include measures of age, sex, height, weight, leg pain dominance and number of falls in the past 6 months. Participants will also be asked about the presence of comorbidities known to have a negative influence of walking capacity as well as previous conservative treatment (e.g., injection, manual therapy). The physical examination will include the assessment of lower limb dermatomes and myotomes as well as paresthesia and osteotendinous reflexes (to document the absence of a peripheral neuropathy).

Table 5.1 - Data collection

	Measures	Baseline assessment	Week 2 assessment	Week 4 assessment	Week 6 assessment	Week 12 assessment
Baseline measurements	Sociodemographic data and physical examination	X	-	-	-	-
Primary outcome	SPWT	X	X	X	X	X
Secondary outcomes	NRS for leg pain intensity	X	X	X	X	X
	NRS for back pain intensity	X	X	X	X	X
	Leg pain dominance	X	-	-	-	-
	FC-SSSQ	X	-	-	X	X
	FC-CPSES	X	-	-	X	X
	FC-HADS	X	-	-	X	X
	QAPPA	X			X	X
	Gait pattern characteristics	X	X	X	X	X
	SPPB	X	-	-	X	X
	Global perceived change	-	X	X	X	X

SPWT = Self-Paced Walking Test, NRS = Numerical Rating Scale, FC-SSSQ = French-Canadian adaptation of the Swiss Spinal Stenosis Questionnaire, FC-CPSES = French-Canadian Chronic Pain Self-Efficacy Scale, FC-HADS = French-Canadian adaptation of the Hospital Anxiety and Depression Scale, QAPPA = Questionnaire d’activité physique pour les personnes âgées [Physical Activity Questionnaire for the Elderly], SPPB = Short Physical Performance Battery

Primary outcome

The primary outcome for this study is walking capacity which will by assessed using the Self-Paced Walking Test (SPWT). The SPWT represents the current gold standard for assessing walking capacity in patients with LSS (Tomkins-Lane & Battié, 2010; Tomkins et al., 2009). During this test, participants will be asked to walk freely on a levelled surface at their own pace until they are forced to stop for a minimum of 3 seconds because of LSS symptoms. Time and distance reached by the participants will be measured. The minimal clinically important change (MCID) reported for the SPWT varies between 319 and 376 meters (Carlesso et al., 2021). As patients with LSS causing NC are at higher risk of fall, participants will walk near a ramp and a research assistant will also walk behind the participant during the walking test to assist if need be.

Secondary outcomes

Patients-reported outcomes measures

Participants will be invited to complete a set of questionnaires assessing physical and psychological PROMs including leg and back pain (numerical rating scale)(Hawker et al., 2011), LSS-related disability (French-Canadian version of the Swiss Spinal Stenosis)(Marchand et al., 2019), self-efficacy (French-Canadian Chronic Pain Self-Efficacy Scale)(Lacasse et al., 2015), physical activity (Questionnaire d'activité physique pour les personnes âgées)(de Souto Barreto et al., 2011), anxiety and depression (French-Canadian adaptation of the Hospital Anxiety and Depression Scale)(Roberge et al., 2013).

Leg and back pain

Leg and back pain intensity will be independently assessed using a 11-point numerical rating scale (NRS) (0 indicating an absence of pain, 10 indicating the worst pain imaginable) (Hawker et al., 2011).

Disability related to LSS

LSS-related disability will be measured using an adapted version of the validated French-Canadian version of the Swiss Spinal Stenosis Questionnaire (FC-SSSQ) (Marchand et al., 2019). This questionnaire is a LSS specific tool composed of three subscales which assess symptom severity, physical function and satisfaction with care. The pain subscale includes seven items of which six are scored using a five-point Likert scale and one (Q7) is scored using 1,3 or 5 points. The physical function subscale includes 5 items scored on a four-point Likert scale. In the proposed study, the satisfaction subscale will be removed because no participants will have undergone surgery. For the symptoms severity and physical function subscales, a higher score indicates greater disability and the FC-SSSQ total possible score without considering the satisfaction subscale is 55 points. We considered that this outcome measure is the most appropriate for patients with LSS causing NC. In fact, the SSSQ have been established as the gold standard questionnaire to assess pain and function (Committee). This questionnaire is also highly correlated with the SPWT (Conway et al., 2011), the standard criterion to assess walking capacity in patient with LSS causing NC (Tomkins et al., 2009).

Self-efficacy

Self-efficacy will be assessed using the validated French-Canadian Chronic Pain Self-Efficacy Scale (FC-CPSES) (Lacasse et al., 2015). Each of its 33 items is measured using a 10-point numerical scale (1 = not at all confident and 10 = totally confident). The FC-CPSES total score ranges from 1 to 10 and is obtained by calculating the mean score of the 33 items. Higher scores indicate higher self-efficacy.

Physical activity

Physical activity level will be assessed using the validated Questionnaire d'activité physique pour les personnes âgées [Physical Activity Questionnaire for the Elderly] (QAPPA). This questionnaire assesses the amount of moderate and vigorous physical activity during the last 7 days (MET-min/week). Following the completion of this questionnaire, participants can be classified into the following categories according to their physical activity volume: high, moderate or low physical activity level (de Souto Barreto, 2013; de Souto Barreto et al., 2011).

Anxiety and depression

Anxiety and depression will be assessed using the validated French-Canadian adaptation of the Hospital Anxiety and Depression Scale (FC-HADS) (Roberge et al., 2013). This questionnaire is a 14-item scale with 7 items assessing anxiety and 7 items assessing depression. Each item is scored from 0 to 3 for a maximum of 21 points for each subscale. A higher score indicates higher anxiety (HADS-A) or higher depression (HADS-D).

Patients' Global Impression of Change

Patient's global impression of change (PGIC) will be measured using a 7-point scale that ranges from 'very much improved' to 'very much worse' with 'no change' as the mid-point (Dworkin et al., 2005; Farrar et al., 2001).

Objectives measures

Walking capacity and gait pattern characteristics

During the SPWT, two synchronized inertial sensors (Physilog®6 – GaitUp, Lausanne, Switzerland, 128Hz) will be placed and attached on the top of each participant's shoe. These inertial sensors include 3-dimension accelerometer, gyroscope and magnetometer which allow the measurement of more than 25 gait parameters including general (e.g. speed, left/right asymmetry, variability and cycle duration), temporal (e.g. stance, swing and double support), spatial (e.g. swing speed, swing width and strike angle) and clearance parameters (maximum heel, maximum and minimum toe clearance).

Lower extremity physical function and balance

Lower extremity physical function and balance will be assessed using the Short Physical Performance Battery (SPPB), a validated test battery among older adults (Freire et al., 2012). This test battery includes standing balance, 4-meter walking at usual pace and repeated sit-to-stand tests. Each of the three tests of the battery is scored from 0 (inability to perform) to 4 (high category of performance) which puts the total score out of 12 (higher score indicates lower extremity function). The standing balance test is divided into three components: side-by-side, semi-tandem and tandem balance. For each component of the standing balance test, participants are asked to maintain the position for a maximum of 10 seconds. The 4-meter walking test at usual pace consists of walking at usual pace on a levelled surface 4-meter hallway. Participants will be asked to perform it twice and the result of the fastest trial will be kept for analysis. The repeated sit-to-stand test consists of performing five sit-to-stand repetitions as fast as possible with arms across the chest. The score for this test is based on the time required to perform fives repetitions. If participants are unable to complete five repetitions or if it takes more than one minute to perform them, the score attributed to this test will be 0.

Sample size

The sample size for this study has been determined based on the continuous primary outcome (walking capacity) using the MCID of 331 meters which represents the MCID at 2 months following nonsurgical treatments according to Carlesso and colleagues (Carlesso et al., 2021). Considering a one-sided significance level of α=0.05, a power of 80% and an attrition rate of 15%, a total of 66 participants (33 per group) will need to be recruited.

Statistical analyses

Baseline characteristics and outcomes measures will be summarized with descriptive statistics for each group. Two-tailed independent sample t tests will be performed to compare group baseline characteristics. Paired factor analyses using analyses of covariance will be performed for each of the outcome measures (primary and secondary). Such analysis ensures that identified confounding factors do not influence intergroup differences. ANOVAs will be used to compare the evolution of walking capacity over weeks. An intention-to-treat method will be used and missing data will be replaced using a multiple imputation method. No additional analyses (e.g., subgroup and adjusted analyses) are planned for this study. Statistical analyses will be conducted using SPSS statistical version 26 for Windows software and the level of significance will be set at a p-value ≤ 0.05.

<u>Adverse events and harms</u>

All adverse events (minor or major) associated with both intervention and usual care will be monitored using open-ended questions. Adverse events are defined as any undesirable experience occurring to a participant, with or without relation to the intervention. These undesirable experiences include an increase in back or leg pain intensity and claudication discomfort. Each adverse event reported by participants throughout the study will be considered and discussed with the research team. Adverse events that are associated with an increase in disability will be reported to the ethics committees. There is no anticipated harm and compensation for trial participation.

<u>Data management</u>

The researchers shall fill in data to the data collection sheet accurately, completely, and timely based on original observations. MH will be responsible to fill in data collection sheets during each evaluation and CT will be responsible to fill in data collection sheets during each intervention. Researchers are responsible for ensuring the accuracy of all data entered and recorder. All data collected during this study are totally confidential and will never allow participants identification. Confidentiality will be assured by replacing the participants' name by an alphanumeric code. The data collected will be stored under lock and key in the evaluation or intervention room (paper documents) or on a secure network with both network and electronic document access protected by passwords under the responsibility of the Chaire de recherche internationale en santé neuromusculosquelettique at the Université du Québec à Trois-Rivières. Only the research members will have access to these data. All of them have signed a confidentiality agreement. All data will be destroyed 5 years after the end of the study. For monitoring and control purposes, research files may be consulted by a person mandated by the CIUSSS MCQ Research Ethics Board or by a person mandated by authorized public agencies. All these persons and organizations adhere to a confidentiality policy. Full name, contact information, and the start and end date of participation for each participant in the project will be kept for one year after the end of the project in a separate directory maintained by the researcher responsible (MH) for this research project. For randomisation purpose, a research assistant will have access to baseline data. This research assistant has also signed a confidentiality agreement.

Plans to give access to the full protocol, participant-level data

Detailed information of the study including study design, eligibility criteria and outcomes measures are currently available to the public on Clinical Trials. Datasets analyzed during the study, statistical code and materials are available from the corresponding author on reasonable request.

Composition of the coordinating center and trial steering committee, and plans for auditing trial conduct

The coordinator of the study is MH. She is responsible for all aspects of local organization including identifying potential recruits and taking consent from participants. In addition to MH, CEC is responsible for the identification of potential recruits in the regional hospital outpatient clinic. CT (certified kinesiologist) is the supervisor of each session of exercises for the intervention group. The project is supervised by MD and AAM. Both are professors at UQTR and are supervising MH's doctoral studies. The local Trial Steering Committee is composed of MH, CT, CEC, AAM and MD. The team discussed the test protocols, the intervention content, and related materials together. The committee will meet each month throughout the study. If there is any modification to the protocol that need to be done or if there is any adverse event, the TSC will discuss the situation as soon as possible and will inform the research ethic committee. The monitoring will be conducted by the principal investigator of the study each month as an audit of trial conduct. There is no Stakeholder and Public Involvement Group for this study.

Dissemination plans

Results will be communicated to participants, healthcare professionals, the public, and other relevant groups via publications in scientific journals, platform presentations and poster presentations during national and international congresses.

DISCUSSION

The interventions for this RCT were designed according to the best available treatment guidelines and best practice recommendations which include the use of education and an individually tailored supervised exercise program (Bussières et al., 2021; Newman et al., 2004). A recent systematic review focusing on multidisciplinary interventions for chronic pain reported that education should be incorporated in future RCTs because of its contribution to the improvement of chronic pain management especially with regard to self-efficacy. This improvement was observed when education was used as either the active or the control intervention (Joypaul et al., 2019). In addition, a previous qualitative study reported that short bouts of education about exercise techniques improved symptoms related to LSS causing NC (Lynch et al., 2018). According to Backstrom and colleagues, education should include information related to LSS such as its definition, symptoms manifestations, the natural course of the condition, the purpose of home exercises, information related to pathophysiology and self-management strategies (Backstrom et al., 2011). Self-management strategies are essential in the management of persistent musculoskeletal conditions such as LSS and should be an important part of education programs (Hutting et al., 2019). Recently, patient education under many forms (e.g., pathoanatomical descriptions, etiologies, self-management strategies, nutrition modifications and physical activity) has been included in RCTs for LSS (Ammendolia et al., 2018; Comer et al., 2013a; Kesänen et al., 2017; Tomkins-Lane et al., 2013). However, there was heterogeneity regarding education content, intervention duration and outcome measures among the studies making it difficult to draw conclusions on the best parameters of education to be used. Building on previous findings, the present protocol study will provide a standardized education program for both groups. This should help patients better understand their condition and why exercises can be used to improve walking capacity. In addition, the use of a standardized education program will allow us to isolate the effect of the exercises on the improvement of walking capacity in patients with LSS causing NC.

Regarding rehabilitation programs, the effectiveness of exercises alone on improving objective walking capacity is still not well established (Bussières et al., 2021). A recent systematic review reported low to moderate-quality evidence for multimodal programs including exercises on improvement of symptoms and function in patients with LSS causing NC (Ammendolia et al., 2022). In addition, another previous RCT showed that the use of supervised exercises provided significantly greater improvement in walking distance, physical function and symptoms severity compared to self-directed exercises (Minetama et al., 2019). Similarly, another RCT of Comer et al. showed that a self-directed home exercise program including flexion and aerobic exercises punctually prescribed by physiotherapists did not systematically improve symptom severity and was no more effective than education and advice (Comer et al., 2013a). However, in most previous RCTs, exercise intensity was not tailored to day-to-day symptoms severity. Thus, the present protocol is innovative in two respects: it includes standardized education for all participants, and it takes into consideration the day-to-day evolution of symptom severity to provide tailored a exercise program.

Previously reported rehabilitation programs usually included aerobic and lower limbs strengthening exercises (Ammendolia et al., 2018; Goren et al., 2010; Marchand et al., 2021; Schneider et al., 2019; Whitman et al., 2006), but did not incorporate balance-strengthening exercises. However, patients with LSS and NC present an increased risk of falls for a variety of reasons, including deconditioning, lower extremity neurological deficits, polypharmacy, environmental hazards, poor vision, and impairments in gait and activities of daily living (Moreland et al., 2003). In addition, a previous study of Thornes et al. showed that there was a large inter-individual variation in balance between patients with LSS and NC, and that gait stability was negatively associated with disability as measured by the ODI (Thornes et al., 2018). Based on those findings and knowing that balance limitations have been identified in 45 to 65% of patients with LSS (Iversen et al., 2009; Truszczyńska et al., 2014), the present protocol will include balance exercises to help decrease the risk of fall in patients with LSS causing NC and to contribute to patient's self-confidence during walking.

Another point to consider when assessing the effectiveness of any intervention is the primary outcome measure. To date, most studies using exercises as the main intervention for LSS used indirect measures of walking capacity such as functional capacity measured by the SSSQ or the Zurich Claudication Questionnaire (ZCQ), leg and back pain intensity, disability measured by the ODI or the global rating of change scale as their primary outcome (Marchand et al., 2021;

Minetama et al., 2019; Schneider et al., 2019; Whitman et al., 2006). Considering that a decrease in walking capacity is considered one of the most bothersome consequence of LSS causing NC (Ammendolia et al., 2017), direct measures of walking capacity using a self-paced walking test should be used when assessing the effectiveness of interventions on functional capacities.

Overall, having a flexible rehabilitation program combining lower limb strengthening and balance exercises should lead to an improvement in walking capacity for patients with LSS causing NC. In addition, it should increase self-efficacy and decrease anxiety. This will also provide patients with a conservative treatment option that takes into consideration the day-to-day fluctuation in symptom severity. To our knowledge, this is the first LSS specific rehabilitation program providing standardized education and graded exercises aimed at improving walking capacity regardless of patients' current health care trajectories.

This study protocol also presents innovative components. Indeed, by adding inertial wearable sensors during the SPWT walking evaluation, this study will provide original and accurate information about gait pattern characteristics of patients with LSS causing NC. By monitoring gait biomechanical parameters throughout the study, we will also be able to determine which ones are modified by exercises and how they are modified. This could eventually help researchers and clinicians better understand the patient's biomechanical adaptations over time as well as the impact of specific exercises on walking capacity or gait pattern characteristics. Findings from this study may eventually lead to improvement in the evaluation and management of patients with LSS causing NC.

TRIAL STATUS

Version: 1 (07/07/2022)

Recruitment (anticipate): from October 1, 2022, to December 31, 2024

Study setting

<u>List of study sites:</u>

1. Chiropratic academic teaching clinic: Université du Québec à Trois-Rivières, Trois-Rivières, Québec, Canada

2. Regional hospital neurosurgery outpatient clinic: Centre intégré universitaire de santé et de services sociaux de la Mauricie-et-du-Centre-du-Québec, Trois-Rivières, Québec, Canada

DECLARATIONS

Ethics approval and consent to participate: "The project received approval from the Human Research Ethics Board of "Université du Québec à Trois-Rivières" (CER-XXX) and all methods were performed in accordance with the relevant guidelines and regulations. All participants provided informed written consent before completing the baseline assessment."

Consent for publication: Not applicable

Availability of data and materials: Original consent form, data and materials are available upon reasonable request to the authors.

Competing interests: The authors declare that they have no competing interests.

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Trial sponsor: Université du Québec à Trois-Rivières which holds indemnity insurance and legal liability.

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The trial sponsor had no influence on the research.

Authors' contributions: All authors have contributed substantially to the manuscript. Study conception and design (all authors), drafting the manuscript (MH, AA, MD), revising it critically for important intellectual content (all authors), and final approval of the version to be published (all authors).

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Chapitre 6 – Article 5, The impact of a rehabilitation program combining education and exercise on walking capacity in patients with lumbar spinal stenosis causing neurogenic claudication: a randomized controlled trial

****Cette version de l'article présente uniquement les données préliminaires du projet (n=44). L'analyse complète des données sera réalisée lorsque tous les participants auront terminé le projet. Le calcul du « sample size » présenté dans cette version est donc celui pour la version finale de l'article. Au moment du dépôt de la thèse, huit participants supplémentaires ont terminé l'ensemble des rencontres et deux sont toujours actifs.*

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Résumé

Contexte : La sténose spinale lombaire (SSL) est une condition dégénérative engendrée par un rétrécissement du canal rachidien. La principale manifestation clinique de la SSL est la claudication neurogène (CN). Les symptômes associés à la CN limitent la capacité de marche et les activités quotidiennes. À ce jour, les options de traitement pour la gestion de la SSL causant la CN vont des approches conservatrices, telles que l'exercice et l'éducation, aux interventions plus invasives comme la chirurgie. Les options conservatrices, incluant des interventions multimodales, sont actuellement recommandées comme traitement de première intention pour la gestion de la SSL causant la CN. La plupart des interventions multimodales comprennent des traitements passifs et actifs. Les traitements passifs, comme la thérapie manuelle, nécessitent du temps pour des rendez-vous en personne et ne favorisent pas l'autogestion des patients. Il est donc essentiel de développer des programmes aidant les patients ayant un diagnostic de SSL avec CN à gérer leurs symptômes au quotidien et à maintenir leurs capacités fonctionnelles.

Objectif : Cette étude visait à évaluer l'efficacité d'un programme de réadaptation de 6 semaines combinant des exercices et de l'éducation sur la capacité de marche des individus ayant un diagnostic de SSL avec CN en comparaison à l'éducation seule.

Méthodes : Quarante-quatre participants âgés de 50 ans et plus, avec un diagnostic de SSL avec CN, seul ou en combinaison avec d'autres types de SSL, confirmé par une évaluation clinique et des examens d'imagerie, ont été recrutés. Les participants devaient être capables de marcher au moins 20 mètres sans aide, mais incapables de marcher 30 minutes en continu. Les participants ont été assignés au hasard dans le groupe d'intervention qui recevait le programme combinant des exercices et de l'éducation ou dans le groupe contrôle qui recevait uniquement l'éducation. La capacité de marche (temps et distance) de même que l'intensité de la douleur aux jambes et au dos, l'incapacité liée à la SSL, le sentiment d'auto-efficacité, l'anxiété, le niveau d'activité physique ainsi que la fonction physique des membres inférieurs et les paramètres de marche ont été mesurés chez tous les participants. Les participants ont été évalués à 5 reprises (évaluation initiale, semaine 2,4,6 et 12). Les comparaisons entre les groupes ont été réalisées à l'aide d'analyses de covariance.

Résultats : Les résultats montrent que les participants du groupe d’intervention ont améliorés leur capacité de marche (temps de marche et distance avant l'apparition des premiers symptômes, ainsi que le temps total de marche) davantage que les participants du groupe contrôle (ps<0.01). L'intervention a également eu un effet positif sur l'incapacité liée à la SSL (p=0.044), l'auto-efficacité (p=0.028) et l'anxiété (p=0.035) en faveur du groupe d'intervention. Aucune différence significative entre les groupes n'a été observée pour la distance totale de marche.

Discussion/Conclusion : Le programme de réadaptation de 6 semaines combinant de l’éducation et des exercices a montré un effet supérieur sur l'amélioration de la capacité de marche par rapport à l'éducation seule. Le programme de réadaptation a également eu un impact positif sur l'incapacité liée à la SSL, l'auto-efficacité et l'anxiété. Le programme de réadaptation fourni aux individus des outils supplémentaires pour les aider à mieux gérer leur condition à long terme.

Mots-clés : Réadaptation, Sténose spinale lombaire, Capacité de marche, Claudication neurogène, Paramètres de marche, Exercice, Éducation.

Abstract

Background: Lumbar spinal stenosis (LSS) is a degenerative condition that results from the narrowing of the spinal canal and its main clinical manifestation is neurogenic claudication (NC). Symptoms related to NC are known to limit walking capacity and daily activities. To date, treatment options for the management of LSS causing NC range from conservative approaches like exercise and education to more invasive ones such as surgery. Conservative options including multimodal interventions are currently recommended as first-line approach for the management of LSS causing NC. To date, most multimodal interventions include both passive and active treatments options. Passive treatment options, such as manual therapy, require time for in-person appointments and does not promote patient self-management. Therefore, there is a need to develop effective programs that could be implemented as home-based options to help individuals with LSS causing NC manage their symptoms and maintain their functional capacities.

Objective: This study aimed to evaluate the effectiveness of a 6-week rehabilitation program combining exercise and education, compared to education alone, on walking capacity in individuals with LSS causing NC.

Methods: Forty-four participants aged 50 and older with a diagnosis of LSS causing NC, alone or in combination with other LSS types, confirmed through clinical assessment and imaging, were recruited. Participants had to be able to walk at least 20 meters without assistance, but not be able to walk continuously for 30 minutes. Participants were randomly allocated to the intervention group who received exercise and education or to the control group who received education only. The primary outcome was walking capacity (time and distance) and secondary outcomes included both patient-reported outcome measures (leg and back pain intensity, disability, self-efficacy, anxiety and physical activity level) and objective physical measures (lower extremity physical function, balance, and walking parameters). Data collection occurred at baseline, week 2, week 4, week 6 and at week 12. Between-group comparisons over time were conducted using analyses of covariance.

Results: Participants in the intervention group had greater improvement in walking time and distance to first symptoms, and total walking time, compared to the control group (ps<0.01). No significant difference was found for total walking distance. The intervention also had a positive effect on LSS-related disability (p=0.044), self-efficacy (p=0.028) and anxiety (p=0.035) in favor of the intervention group.

Discussion/conclusion: The 6-week rehabilitation program combining education and exercise showed a superior effect on the improvement of walking capacity than education alone. The rehabilitation program also had a positive impact on LSS-related disability, self-efficacy, and anxiety. The proposed rehabilitation program could provide individuals with additional tools to self-manage their condition over time.

Keywords: *Rehabilitation, Lumbar Spinal Stenosis, Walking Capacity, Neurogenic Claudication, Walking parameters, Exercise, Education*

INTRODUCTION

Lumbar spinal stenosis (LSS) is a common degenerative musculoskeletal condition caused by various age-related changes in the lower spine (Katz et al., 2022; Kobayashi, 2014), leading to the narrowing of the spinal canal (Katz et al., 2022). Symptomatic LSS is commonly referred to as neurogenic claudication (NC), which is marked by unilateral or bilateral lower limb symptoms including pain, cramping, numbness, and weakness (Kobayashi, 2014). These symptoms are typically triggered by prolonged standing or walking and alleviated by sitting, bending forward, or lying down (Christine M. Comer et al., 2009; Kobayashi, 2014). Because of its symptomatology, LSS is known to be associated with important walking limitations and disability (Kim et al., 2011; Winter et al., 2010), which are two of the most common concerns reported by individuals with LSS causing NC (Ammendolia et al., 2017). Walking limitations associated with LSS causing NC are often described as a reduction in walking capacity, which refers to an individual's ability to walk a given distance or duration (Organization, 2007; C. C. Tomkins et al., 2009). This decrease in walking capacity impacts individuals with LSS and NC daily, contributing to negative emotions like frustration and anxiety, and reducing their participation in various daily tasks, such as lifting, sleeping, and household, as well as and social activities. (Ammendolia et al., 2017; Norden et al., 2017).

To date, most treatment options proposed to individuals living with LSS causing NC aim to improve walking capacity or function, or to reduce LSS-related pain (C. M. Comer et al., 2009; Machado et al., 2015; Masakazu Minetama et al., 2019; Thornes et al., 2020). These treatment options range from conservative approaches, such as exercise and manual therapy, to more invasive ones, like surgery (Katz et al., 2022). While surgery is the preferred treatment for certain subgroups of patients with moderate, severe or worsening leg symptoms, neurological deficits or declining mobility (Comer et al., 2022; Kawakami et al., 2023), conservative care plays a crucial role before surgical intervention to limit pain or functional decline. Furthermore, not all individuals will require or are eligible for surgery due to other health conditions. Given that the natural progression of LSS causing NC is generally favorable for most individuals, with around 60% improving or remaining stable and about 30% worsening (Minamide et al., 2013; Per Wessberg & Karin Frennered, 2017), conservative treatments have been recommended as the first-line approach for managing the condition (M. Fornari et al., 2020). Despite the insufficient number of high-quality randomized controlled trials (RCT) to inform clinical practice guidelines on the effectiveness of conservative treatment options (Ammendolia et al., 2022), recent expert consensus and clinical guidelines for the management of LSS causing NC have concluded that conservative approaches, such as exercise and education, should be considered when possible(Comer et al., 2024; M. Fornari et al., 2020; Kawakami et al., 2023), as they are known to provide global health benefits (Kawakami et al., 2023) and very few adverse side effects (M. Fornari et al., 2020).

In the last decades, few trials involving exercise for the management of LSS have been conducted. Most of these studies have either exclusively included individuals with LSS causing NC who were awaiting surgery (Marchand et al., 2021) or, conversely, excluded this subgroup (Ammendolia et al., 2018; Thornes et al., 2020; Williamson et al., 2022), leaving many individuals who could also benefit from such interventions unconsidered in both cases. In addition, these studies often combined the use of active treatments such as exercise with passive treatments, such as manual therapy (Masakazu Minetama et al., 2019; Schneider et al., 2019; Whitman et al., 2006), making it challenging to isolate the specific effect of active treatments. Passive treatment options, such as manual therapy, also require time for in-person appointments and does not promote patient self-management. Therefore, there is a need to develop programs that will help individuals with LSS causing NC to manage their symptoms and to maintain their functional capacities.

Among the recommended treatment options, the combination of exercise and education is promising for several reasons. First, exercise interventions that include aerobic exercises, flexion-based exercises and trunk muscles control exercises have shown health benefits in alleviating pain, and improving physical function, activities of daily living, and quality of life in individuals with LSS causing NC (C. M. Comer et al., 2009; Kawakami et al., 2023). Tailored exercises are also known as a valuable tool for managing daily symptoms (Teo et al., 2022) in addition to improving walking capacity (Jacobi et al., 2021; Teo et al., 2022) and providing general health benefits (Kawakami et al., 2023). Second, education is considered a key component for the self-management of chronic musculoskeletal conditions (Bussières et al., 2021; Rousing et al., 2019). In the context of LSS causing NC, the specific components of education still need to be developed and investigated (Comer et al., 2022). Education has the potential to help individuals understand their condition, the natural course of LSS causing NC, the available treatment options (e.g., exercise) and the treatment timeline (e.g., trying conservative treatments before considering injections or surgery). Previous studies have reported that individuals with LSS causing NC desire more information about their condition and treatment options (Comer et al., 2022; Lyle et al., 2017). When combined, exercise and education have the potential to provide individuals with LSS causing NC with tools to help them manage their condition daily. In addition, including individuals with LSS causing NC in the decision-making process can improve adherence to treatments as it can help them to better understand the condition and its progression.

To the best of our knowledge, there are no trials assessing the effects of a rehabilitation program combining exercise and education compared to education alone. For this reason, the aim of the present study is to evaluate the effectiveness of a 6-week rehabilitation program combining education and exercise compared to education alone on walking capacity in individuals with LSS causing NC. We hypothesized that a 6-week rehabilitation program combining education and exercise will have a superior effect on walking capacity compared to education alone and that the effect will persist for up to 12 weeks.

METHODS

Study design, recruitment, and ethical considerations

The study was a single-centre, prospective randomized controlled parallel-group clinical trial. The trial was carried out at the research facility of the Université du Québec à Trois-Rivières (UQTR) in Canada. Participants enrollment started in January 2023, with the last follow-up in September 2024. Participants were recruited from collaborating clinics (a chiropractic university teaching clinic and a regional hospital neurosurgery outpatient clinic), as well as through advertisements in local newspapers and on social media. All participants were screened for eligibility criteria over the phone before being scheduled for their first appointment.

The clinical trial protocol has been previously published (Houle et al., 2022) and the study received approval from the Centre Intégré Universitaire de Santé et de Services Sociaux de la Mauricie et du Centre-du-Québec (CIUSSS MCQ) research ethics committee (CÉR-2023-649) and from the Human Research Ethics Board of UQTR. The study was also registered at ClinicalTrials.gov (NCT05513326) on August 22nd, 2022. This study was conducted in accordance with the Helsinki Declaration. Written informed consent was obtained from all participants before completion of the baseline assessment. The study procedures followed all relevant guidelines and regulations.

Participants

We included individuals aged 50 years or older with a diagnosis of degenerative central lumbar spinal stenosis (LSS), either alone or in combination with other types of LSS (e.g., foraminal or lateral recess) or with spondylolisthesis. LSS could affect one or multiple vertebral levels. The diagnosis was confirmed through clinical history, physical examination, and relevant imaging (MRI or CT scan). Individuals were required to have NC associated with LSS, as well as signs and symptoms present for at least 3 months. Additional inclusion criteria included being able to walk at least 20 meters without assistance, but not being able to walk continuously for 30 minutes and be willing to attend 3 intervention sessions per week over a period of 6 weeks. Individuals also needed to be able to speak and understand French and be able to provide informed written consent. Exclusion criteria included the presence of congenital LSS, traumatic or pathological causes of LSS, symptomatic osteoarthritis (hip or knee) causing limitation in walking capacity, neurological diseases affecting walking capacity, such as Parkinson's disease, uncontrolled diabetes, heart failure, intermittent claudication of vascular origin, impaired cognitive capacity, and history of back or lower extremity surgery within the past 3 months.

Randomization and blinding

Participants were randomly allocated to the intervention group which received a 6-week rehabilitation program combining education and exercise or to the control group, which received only education. Minimization and randomization were performed after the baseline assessment using a computer-generated list of random numbers, which were placed into sealed and opaque envelopes, numbered by an independent research assistant. Each envelope was opened in front of the participants at the end of the baseline assessment by a different independent research assistant. While participants were not blinded to their intervention allocation, the specific exercise content of the sessions was disclosed exclusively to those in the intervention group to prevent any potential cross-contamination between groups. The first author was responsible of outcomes measurement throughout the study and was blind to the group allocation. All details regarding randomization, minimization and blinding have been published previously (Houle et al., 2022).

Interventions

All participants, regardless of group allocation (intervention or control), received two one-on-one education sessions, each lasting approximately 20 minutes These sessions took place during weeks 2 and 4 and covered information on the pathophysiology of LSS and NC, along with the expected natural progression, common symptoms, pain management techniques for daily activities (such as body positioning while walking or sleeping), and recommendations for physical activity. More details about the education program are presented in Supplementary File #1 (*Annexe I de la thèse*). All participants were also instructed to maintain their usual care routines. All treatments received by participants were monitored throughout the study period.

Participants in the intervention group were offered individually supervised training sessions over a 6-week period. These sessions took place three times a week, each lasting 30 minutes. Each week, one session was conducted at UQTR's outpatient clinic, while the other two sessions were offered online through the participant's preferred telecommunication platform (e.g., Zoom (Zoom Video Communications, Inc., San Jose, CA, USA)). All sessions were supervised by a certified kinesiologist and a typical training session included 5 minutes of warm-up, followed by 5 exercises focused on strengthening the lower limbs, 2 balance exercises (both static and dynamic), and 3 stretching exercises for the lower limbs. The difficulty level of each exercise was adjusted according to the participant's individual capacity to ensure safety and appropriateness, allowing for gradual progression over time. The general progression of each exercise is presented in Supplementary File #2 (*Annexe J de la thèse*). Adherence to the exercise program was recorded in the kinesiologist's logbook along with information regarding exercise levels, number of sets and repetitions, and perceived pain intensity and location (e.g., back or leg). Participants in the control group were not discouraged from engaging in physical activity or exercise during the trial.

Outcomes

Sociodemographic data were collected through verbal questioning and self-reported questionnaires during the baseline assessment, with a researcher available to clarify any questions. The impact of the rehabilitation program was evaluated using both patient-reported outcome measures (PROMs) and objective physical assessments. All PROMs and objective physical measures were collected at UQTR's research facility at different moments during the trial (see Figure 6.1 for details).

The primary outcome was the walking capacity measured using the Self-Paced Walking Test (SPWT) (Tomkins-Lane & Battié, 2010; Christy C Tomkins et al., 2009). Walking capacity was measured using the time and distance to the onset of first NC symptoms (increase or onset of symptoms), as well as the total walking time and distance. Regarding secondary outcome measures, mean back and leg pain intensity during the last seven days, as well as current back and leg pain intensity, were measured using the 11-point Numerical Rating Scale (NRS) (Hawker et al., 2011). All other PROMs were assessed using the validated French version of the questionnaires. Theses PROMS included LSS-related disability (French-Canadian version of the Swiss Spinal Stenosis) (Marchand et al. 2019), self-efficacy (French-Canadian Chronic Pain Self-Efficacy Scale) (Lacasse et al., 2015), physical activity (Questionnaire d'activité physique pour les personnes âgées [Physical Activity Questionnaire for the Elderly]) (de Souto Barreto et al., 2011), anxiety and depression (French-Canadian adaptation of the Hospital Anxiety and Depression Scale) (Roberge et al., 2013), and patients' global impression of change (7-point scale) (Dworkin et al., 2005; Farrar et al., 2001). The objective physical measures included gait pattern characteristics assessed with inertial sensors (Physilog®6 – GaitUp) and lower extremity physical function and balance (Short Physical Performance Battery) (Freire et al., 2012). The study protocol offers additional details on the scoring and interpretation of selected outcomes (Houle et al., 2022).

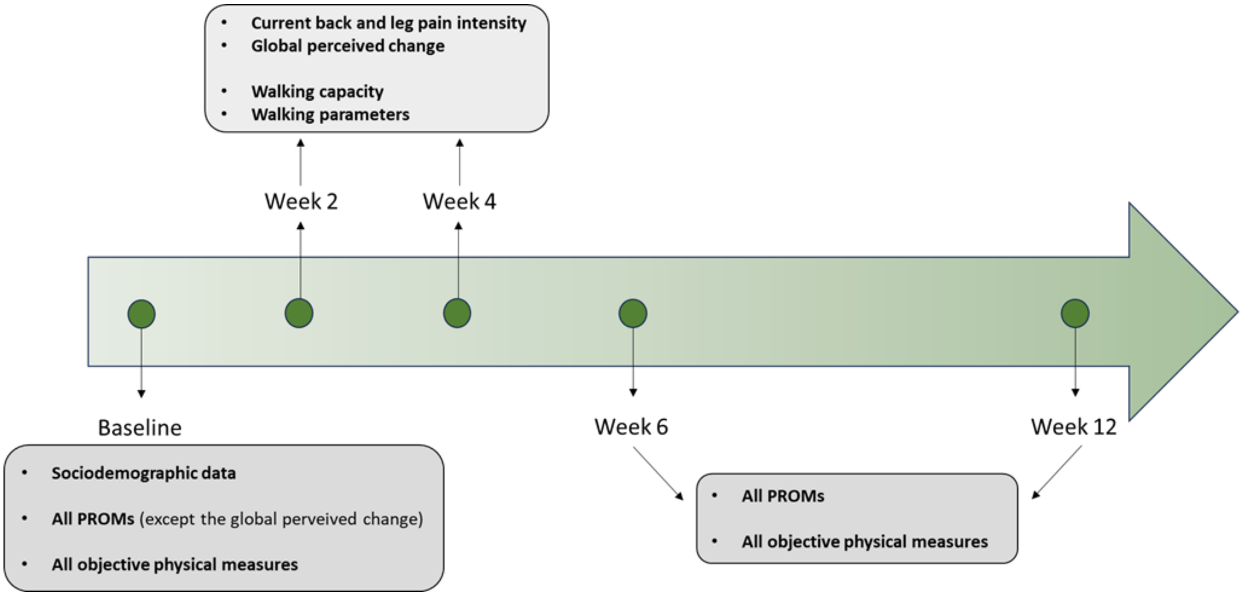

Figure 6.1 - Study timeline for the measurement of PROMs and objective physical measures

Sample Size

The sample size for this study was determined based on the primary outcome of walking capacity, using the minimal clinically important change (MCID) of 331 meters, which represents the MCID at 2 months after nonsurgical treatments, according to Carlesso and colleagues (Carlesso et al., 2021). With a one-sided significance level of $\alpha = 0.05$, a power of 80%, and an attrition rate of 15%, a total of 66 participants (33 per group) were needed.

Statistical methods

The normality of data distribution was assessed using the Kolmogorov-Smirnov test and by visual inspection of the corresponding histograms for each dependent variable. The Box-cox transformation was applied to the dependant variables to achieve normality and ensure equal group variance when necessary (Marimuthu et al., 2022). Baseline sociodemographic data, PROMs and objective physical measures were summarized with descriptive statistics (mean and standard deviation) for each group. For between-group comparisons of sociodemographic data and PROMS, two-tailed independent t-tests were used for continuous variables while chi-square tests were used for categorical variables. Given that weight is a factor known to influence walking parameters and walking capacity (Samson et al., 2001), it was used as a covariate in the between-group comparisons of baseline walking capacity, walking parameters and lower extremity physical function and balance. Mixed analyses of variances (ANOVAs) were conducted for between-group comparison over time for PROMs, while mixed analyses of covariances (ANCOVAs) were conducted for between-group comparisons over time for walking capacity and objectives physical measures, using weight as a covariate. Whenever necessary, Bonferroni post hoc tests were conducted. An intention-to-treat approach was used, and overall missing data (19.29%) were addressed using multiple imputation, with an aggregate of 1000 imputed datasets used to conduct the analyses. Statistical analyses were conducted using SPSS version 29 for Windows (IBM, Armonk, NY), with significance set at a p-value ≤ 0.05.

RESULTS

Between January 2023 and September 2024, a total of 52 individuals with LSS causing NC contacted us for the project. Among them, 44 were deemed eligible and randomly assigned to the intervention (n = 23) or control group (n = 21). Figure 6.2 illustrates the flow of participants throughout the study, including the reasons for non-participation and dropout. All 44 participants took medication for symptoms attributable to LSS causing NC ranging from nonsteroidal anti-inflammatory drugs to anticonvulsants such as gabapentin and pregabalin) and five (two in the intervention group and three in the control group) received injections during the course of the study.

Sociodemographic data and baseline PROMs

There were no significant between-group differences in sociodemographic data and baseline PROMs, except for weight (p=0.007) and body mass index (BMI) (p = 0.034), which were lower in the intervention group. Table 6.1 provides the sociodemographic data and baseline clinical outcomes for all participants.

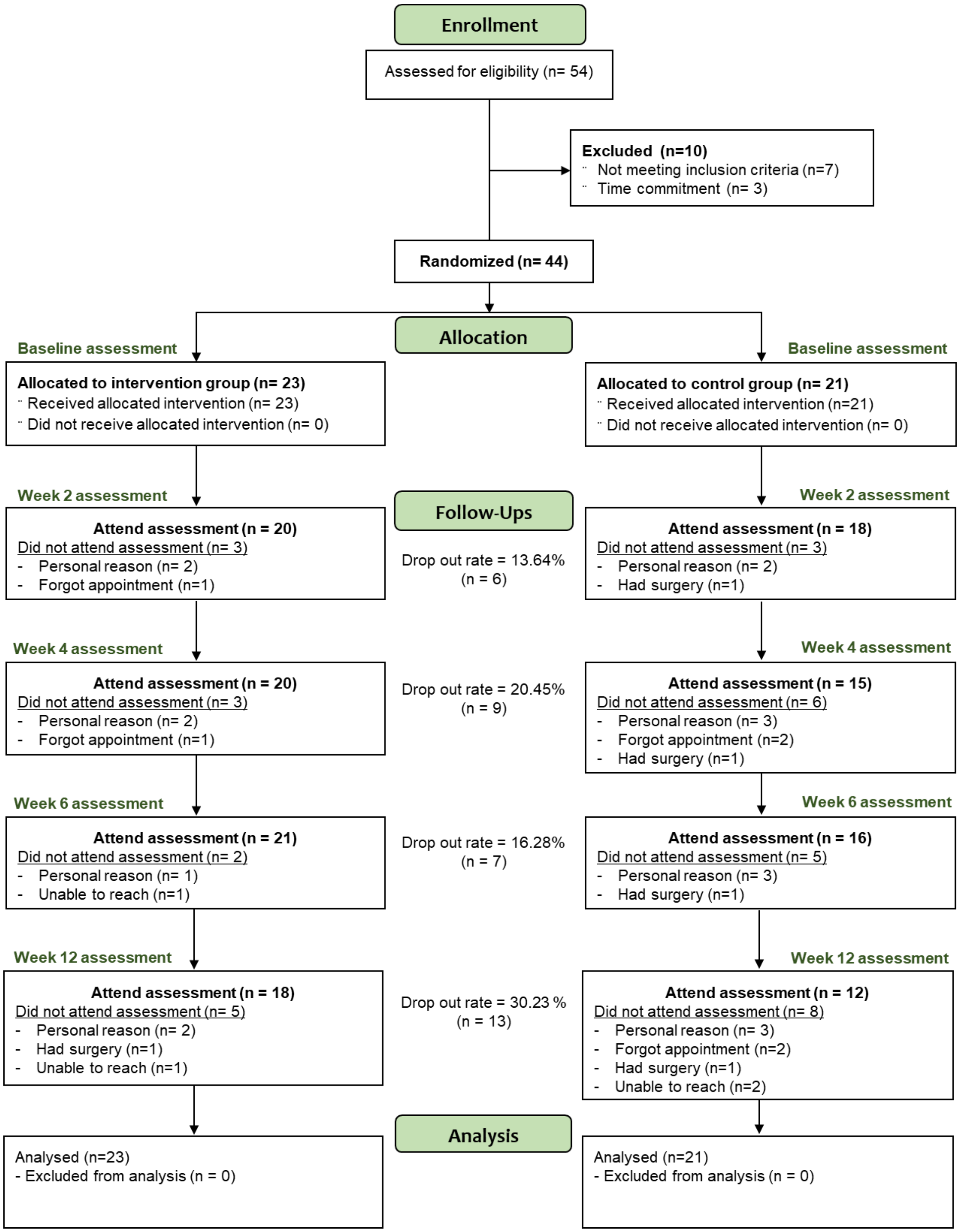

Figure 6.2 - CONSORT flowchart for reporting RCT

Table 6.1 - Sociodemographic and baseline PROMs

	Intervention group (n = 23)	**Control group (n=21)**	**p-value**
Sociodemographic data			
F : M ratio	15 : 8	11 : 10	0.387
Age (years)	67.52 ± 7.00	60.71 ± 5.21	0.096
Height (m)	1.65 ± 0.10	1.68 ± 0.11	0.304
Weight (kg)	76.32 ± 12.84	90.36 ± 19.65	**0.007**
BMI (kg/m^2)	28.17 ± 5.00	31.99 ± 6.50	**0.034**
Number of falls in the last 6 months (yes : no)	5 : 18	5 : 16	0.870
Use of walking aid (yes : no)	3 : 20	6 : 15	0.202
Employment situation			
Currently working (yes : no)	4 : 19	2 : 19	0.488
Minimisation criteria			
Controlled diabetes – n (%)	3 (13.04)	6 (28.57)	0.713
Smoker – n (%)	3 (13.04)	2 (9.52)	0.202
COPD – n (%)	1 (4.35)	1 (4.76)	0.947
Stroke - n (%)	1 (4.35)	0 (0.00)	0.334
Baseline PROMs			
Weekly days with pain (/7)	7.00 ± 0.00	6.70 ± 0.98	0.186
Mean back pain intensity in the last 7 days (/10)	5.07 ± 2.01	4.17 ± 2.58	0.203
Mean leg pain intensity in the last 7 days (/10)	5.28 ± 1.79	4.83 ± 2.37	0.480
Current back pain intensity (/10)	2.96 ± 2.65	2.14 ± 2.43	0.296
Current leg pain intensity (/10)	3.15 ± 2.41	2.95 ± 2.85	0.802
FC-QSSL (/55)	32.48 ± 4.22	35.57 ± 5.94	0.051
FC-CPSES (/33)	7.66 ± 1.72	7.29 ± 1.08	0.405
FC-HADS anxiety (/21)	6.78 ± 2.98	6.67 ± 4.13	0.915
FC-HADS depression (/21)	4.26 ± 2.80	5.86 ± 3.43	0.097
QAPPA (low PAL : moderate PAL : high PAL)	7 : 15 : 1	13 : 7 : 1	0.099

F = female, M=male, BMI = Body Mass Index, COPD = Chronic Obstructive Pulmonary Disease, PROMS= Patients-Reported Outcomes Measures, FC-QSSL = French-Canadian version of the Swiss Spinal Stenosis, FC-CPSES = French-Canadian Chronic Pain Self-Efficacy Scale, FC-HADS = French-Canadian adaptation of the Hospital Anxiety and Depression Scale, QAPPA = Questionnaire d'activité physique pour les personnes âgées [Physical Activity Questionnaire for the Elderly

Table 6.2 provides baseline information on walking capacity outcomes (time and distance), gait pattern characteristics, and lower extremity physical function and balance. There was no significant difference between the groups for all walking capacity outcomes, lower extremity physical function, and balance, as well as for gait pattern characteristics, except for stride length (p=0.022), speed (p=0.023), and heel-strike pitch angle (p=0.018), which were respectively longer, faster, and higher in the intervention group compared to the control group.

Table 6.2 - Baseline walking capacity, gait pattern characteristics and lower extremity physical function and balance for all participants

	Intervention group (n = 23)	**Control group (n = 21)**	**ANCOVA p-value**
Walking capacity			
Walking time to symptoms (sec)	139.83 ± 104.18	120.95 ± 153.01	0.147
Total walking time (sec)	596.83 ± 321.65	465.62 ± 432.26	0.101
Walking distance to symptoms (m)	145.74 ± 117.32	114.69 ± 166.30	0.071
Total walking distance (m)	621.11 ± 343.88	464.62 ± 549.72	0.076
Lower extremity physical function and balance			
SPPB (/12)	7.91 ± 1.09	6.98 ± 1.89	0.092
Gait pattern characteristics			
Cadence (steps/min)	106.32 ± 9.98	97.98 ± 10.56	0.076
Stride length (m)	1.15 ± 0.15	0.98 ± 0.23	**0.022**
Speed (m/s)	1.04 ± 0.19	0.85 ± 0.23	**0.023**
Stance phase (% cycle)	63.61 ± 9.68	66.11 ± 4.30	0.108
Swing phase (% cycle)	36.39 ± 2.41	33.89 ± 4.30	0.108
Double support (%)	26.99 ± 4.20	31.57 ± 8.19	0.131
Peak angular velocity (°/s)	367.94 ± 62.18	335.05 ± 75.32	0.252
Heel-strike pitch angle (°)	22.32 ± 3.86	19.33 ± 4.52	**0.018**
Toe-off pitch angle (°)	-66.69 ± 7.89	-62.86 ± 9.64	0.305
Maximum heel clearance (m)	0.26 ± 0.02	0.25 ± 0.05	0.629
Minimum toe clearance (m)	0.02 ± 0.01	0.02 ± 0.01	0.102

SPPB = Short Physical Performance Battery; Peak angular velocity refers to the maximal angular velocity of the foot during the swing, between maximum heel clearance and minimum toe clearance.

Primary outcomes and estimation of intervention effect

Main effect of Time

After adjusting for weight, there was no main effect of time for walking time to first symptoms (p=0.679), total walking time (p=0.310), walking distance to first symptoms (p=0.560), and total walking distance (p=0.157).

Main effect of Group

After adjusting for weight, there was a main effect of group for walking time to first symptoms ($F_{(1, 41)}$ = 6.876, p = 0.12, η^2 = 0.144), total walking time ($F_{(1, 41)}$ = 6.008, p = 0.019, η^2 = 0.128), walking distance to first symptoms ($F_{(1, 41)}$ = 7.242, p = 0.010, η^2 = 0.150) and total walking distance ($F_{(1, 41)}$ = 5.199, p = 0.028, η^2 = 0.113) indicating that the intervention group walked for a significantly longer time and further than the control group.

Group x Time interaction

There was also a significant Group x Time interaction for walking time to first symptoms ($F_{(4, 41)}$ = 4.131, p = 0.003 , η^2 = 0.092), total walking time ($F_{(4, 41)}$ = 7.338, p = 0.010, η^2 = 0.152), and walking distance to first symptoms ($F_{(4, 41)}$ = 4.405, p = 0.002, η^2 = 0.097), indicating there was a significant group difference over time, with the intervention group showing greater improvement. Post-hoc analysis showed that the intervention group experienced greater improvement in walking time to first symptoms starting from week 4 (mean difference = 257.143 sec, standard error (SE)= 121.668, p = 0.041, 95% CI [11.428, 502.857]), continuing through week 6 (mean difference = 380.887 sec, SE = 110.183, p = 0.001, 95% CI [158.369, 603.406]) and week 12 (mean difference = 275.213, SE = 121.485, p = 0.029, 95% CI [29.868, 520.557]). Post-hoc analysis also showed that the intervention group had a longer total walking time compared to the control group at week 2, with a mean difference of 319.248 sec (SE = 140.426, p = .028), 95% CI [-602.843, -35.653]. At week 4, the difference increased (mean difference = 418.810 sec, SE = 159.136, p = .012, 95% CI [-740.192, -97.428]), and by week 12, the intervention group continued to walk significantly longer than the control group (mean difference = 478.077 sec, SE = 167.140, p = .007, 95% CI [-815.623, -140.532]). For walking distance to first symptoms, post-hoc analysis showed that at week 4, the intervention group walked longer before experiencing their first symptoms compared to the control group, with a mean difference of 293.619 m (SE = 127.959, p = .027, 95% CI [-552.037, -35.202]). At week 6, the difference between groups increased (mean difference = 447.944 m, SE = 130.103, p = .001, 95% CI [-710.693, -185.195]), and at week 12, the intervention group continued to walk significantly further than the control group (mean difference = 330.266 m, SE = 150.564, p = .034, 95% CI [-634.337, -26.195]).

There was no significant Group x Time interaction for total walking distance ($F_{(4, 41)} = 1.648$, $p = 0.165$, $\eta^2 = 0.039$). Figures 6.3 and 6.4 present between-group comparison over time for walking time to first symptoms, total walking time, walking distance to first symptoms and total walking distance.

Secondary outcomes and estimation of intervention effect

Table 6.3 provides information regarding between-group comparison over time for continuous PROMs while table 6.4 provides information regarding between-group comparison overt time for objective physical measures. Means and standard deviations are presented for each time point. Overall, the intervention had a positive effect on LSS-related disability (p=0.044), self-efficacy (p=0.028) and anxiety (p=0.035) in favor of the intervention group. Regarding physical activity level, participants in the intervention group reported greater level of physical activity than the control group after 6 weeks (p=0.011) and this difference remained at 12 weeks (p=0.046).

Participants' compliance with the intervention

A total of 12 participants completed all 18 training sessions as planned, achieving a compliance rate of 52.17%. Ten participants attended more than 50% of the training sessions (ranging from 10 to 17 sessions), while one participant completed less than 50% (only completing one training session). Out of 414 possibles training sessions, participants completed 360 (86.96%) sessions, with a mean of 15.65 sessions per participant.

Fig. 3A)

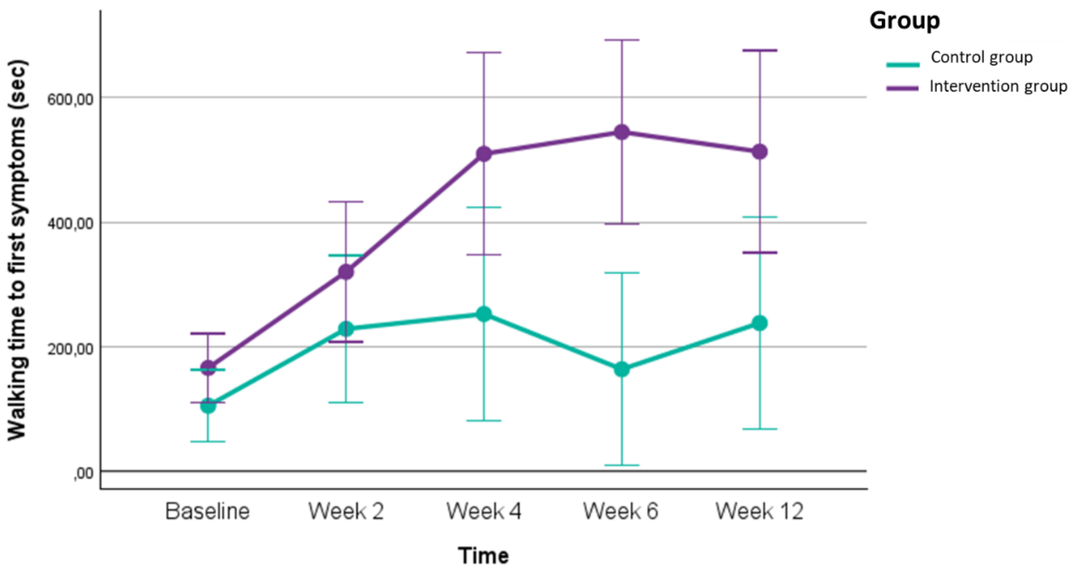

Fig. 3B)

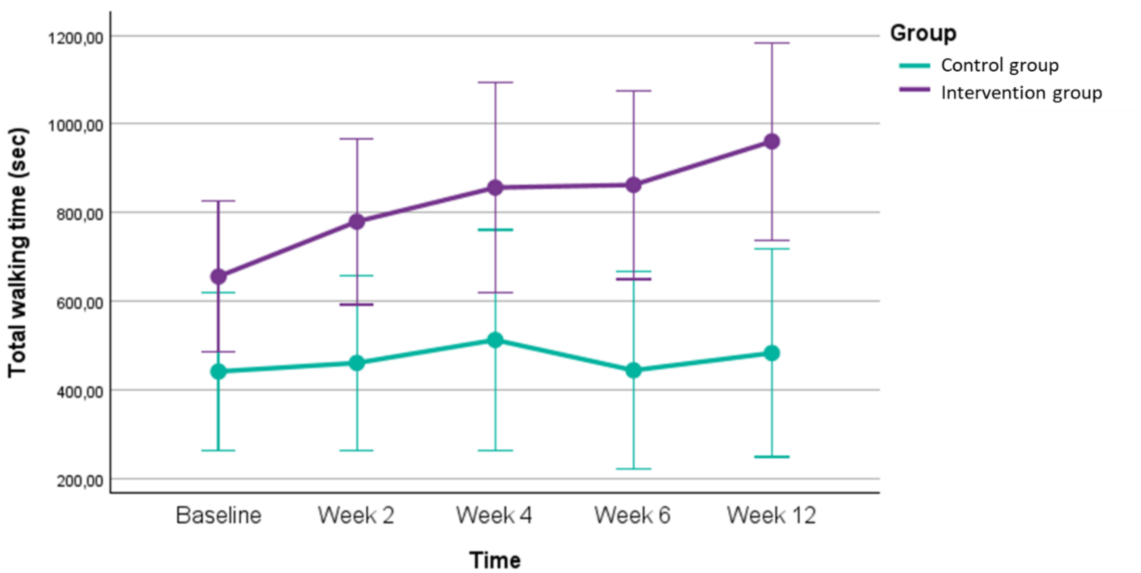

Figure 6.3 - Between-group comparisons over time for A) walking time to first symptoms (mean, 95% CI) and B) total walking time (mean, 95% CI)

Fig. 4A)

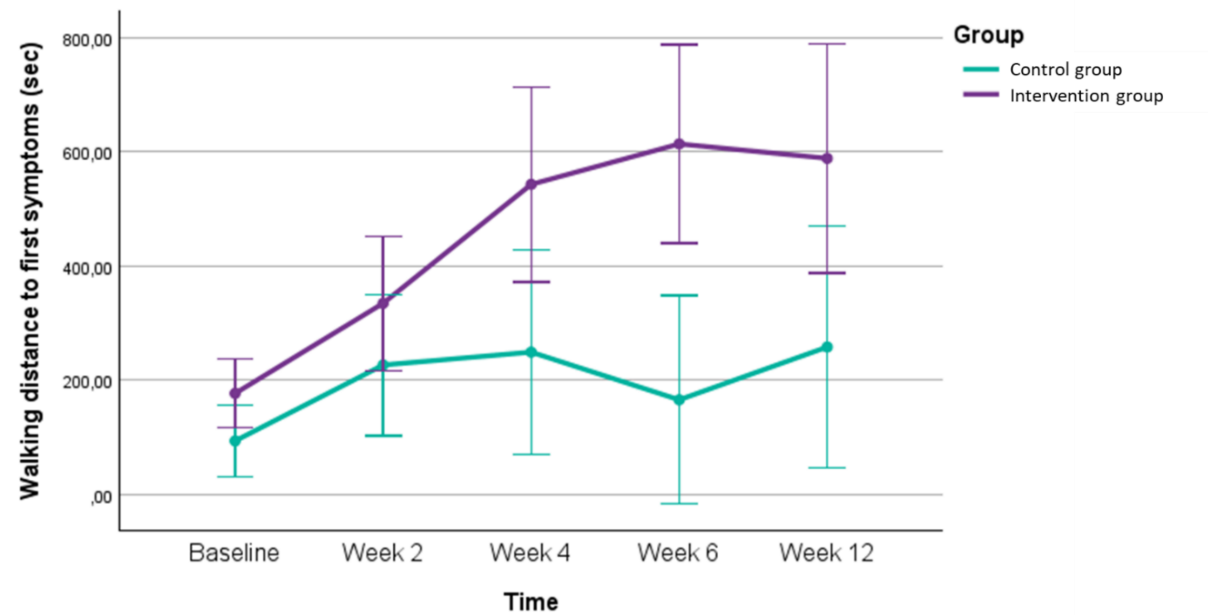

Fig. 4B)

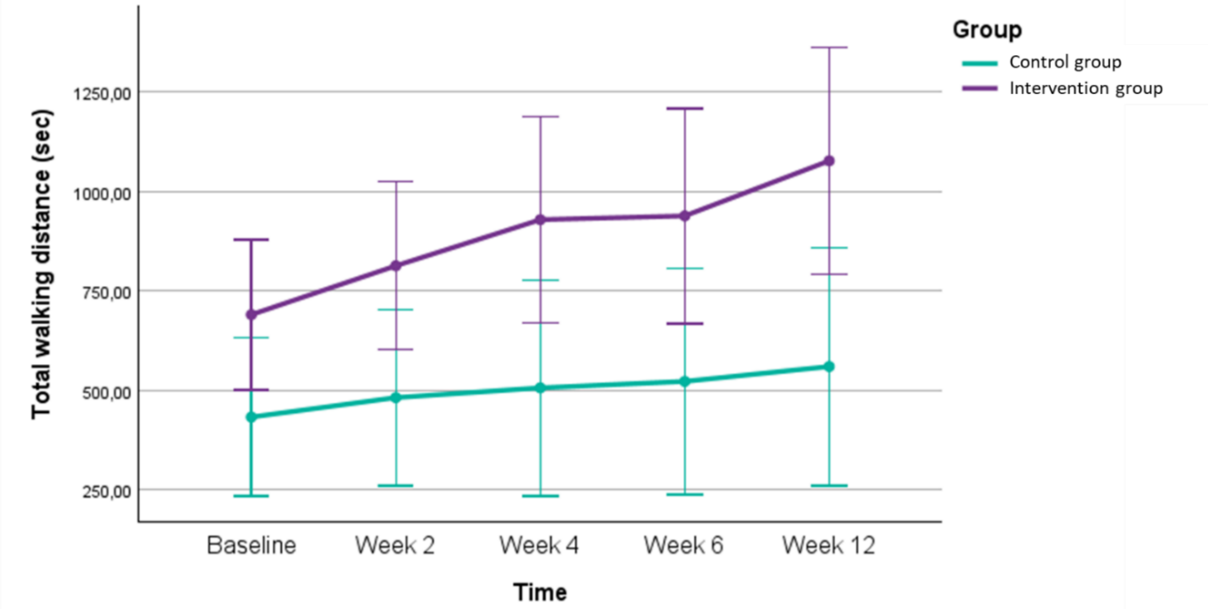

Figure 6.4 - Between-group comparisons for A) walking distance to first symptoms (mean, 95% CI) and B) total walking distance (mean, 95% CI)

Table 6.3 - Between-group comparisons over time for clinical outcomes

Variable	Time	Intervention group (n = 23) Mean ± SD	Control group (n = 21) Mean ± SD	Main effect of time (p)	Main effect of group (p)	Group x Time (p)
Current back pain intensity (/10)	**Baseline**	2.96 ± 2.65	2.14 ± 2.43	0.893	0.874	0.202
	Week 2	3.03 ± 2.04	3.08 ± 2.33			
	Week 4	2.57 ± 2.68	2.72 ± 2.62			
	Week 6	2.48 ± 2.39	3.38 ± 2.60			
	Week 12	2.61 ± 2.64	2.76 ± 2.26			
Current leg pain intensity (/10)	**Baseline**	3.15 ± 2.41	2.95 ± 2.85	0.529	**0.016**	0.152
	Week 2	2.30 ± 1.77	4.33 ± 2.80			
	Week 4	2.25 ± 2.47	3.28 ± 2.48			
	Week 6	2.49 ± 2.80	3.56 ± 2.59			
	Week 12	1.72 ± 1.61	3.40 ± 2.30			
FC-QSSL (/55)	**Baseline**	32.48 ± 4.22	35.57 ± 5.94	**< 0.001**	**< 0.001**	**0.044**
	Week 6	25.96 ± 4.49	32.54 ± 6.51			
	Week 12	25.91 ± 4.94	31.59 ± 6.50			
FC-CPSES (/33)	**Baseline**	7.66 ± 1.72	7.29 ± 1.08	**0.004**	**0.002**	**0.028**
	Week 6	8.43 ± 1.00	7.24 ± 1.17			
	Week 12	8.76 ± 0.89	7.47 ± 1.14			
FC-HADS anxiety (/21)	**Baseline**	6.78 ± 2.98	6.67 ± 4.13	**0.011**	0.301	**0.035**
	Week 6	5.22 ± 2.15	6.77 ± 3.55			
	Week 12	4.96 ± 2.67	6.38 ± 4.03			
FC-HADS depression (/21)	**Baseline**	4.26 ± 2.80	5.86 ± 3.43	**0.050**	**0.008**	0.131
	Week 6	2.87 ± 2.82	5.84 ± 3.79			
	Week 12	2.96 ± 2.53	5.57 ± 3.54			

FC-QSSL = French-Canadian version of the Swiss Spinal Stenosis, FC-CPSES = French-Canadian Chronic Pain Self-Efficacy Scale, FC-HADS = French-Canadian adaptation of the Hospital Anxiety and Depression Scale, QAPPA = Questionnaire d'activité physique pour les personnes âgées [Physical Activity Questionnaire for the Elderly

Table 6.4 - Between-group comparisons over time for lower extremity physical function and balance and gait pattern characteristics

Variable	Time	Intervention group (n = 23)	Control group (n = 21)	Main effect of time (p)	Main effect of group (p)	Group x Time (p)
		Mean ± SD	Mean ± SD			
SPPB (/12)	Baseline	7.91 ± 1.09	6.98 ± 1.89	0.494	0.029	0.739
	Week 6	8.92 ± 1.14	7.68 ± 2.07			
	Week 12	8.93 ± 1.17	8.23 ± 1.26			
Cadence (steps/min)	Baseline	106.32 ± 9.98	97.98 ± 10.56	0.251	**0.017**	0.982
	Week 2	107.34 ± 9.07	99.46 ± 7.62			
	Week 4	109.93 ± 8.91	101.49 ± 6.89			
	Week 6	108.74 ± 9.71	101.86 ± 6.12			
	Week 12	107.78 ± 9.52	100.22 ± 8.39			
Stride length (m)	Baseline	1.15 ± 0.15	0.98 ± 0.23	0.842	0.080	0.103
	Week 2	1.14 ± 0.12	1.07 ± 0.20			
	Week 4	1.16 ± 0.14	1.04 ± 0.17			
	Week 6	1.17 ± 0.14	1.10 ± 0.21			
	Week 12	1.18 ± 0.15	1.11 ± 0.15			
Speed (m/s)	Baseline	1.04 ± 0.19	0.85 ± 0.23	0.479	0.069	0.242
	Week 2	1.03 ± 0.17	0.92 ± 0.23			
	Week 4	1.08 ± 0.19	0.91 ± 0.19			
	Week 6	1.08 ± 0.19	0.97 ± 0.25			
	Week 12	1.09 ± 0.20	0.99 ± 0.20			
Stance phase (% cycle)	Baseline	63.61 ± 9.68	66.11 ± 4.30	0.941	0.107	0.501
	Week 2	63.73 ± 1.95	64.40 ± 2.79			
	Week 4	63.31 ± 2.47	64.85 ± 2.42			
	Week 6	63.02 ± 2.24	64.71 ± 2.77			
	Week 12	63.30 ± 1.99	64.54 ± 1.64			
Swing phase (% cycle)	Baseline	36.39 ± 2.41	33.89 ± 4.30	0.927	0.104	0.509
	Week 2	36.28 ± 1.95	35.60 ± 2.79			
	Week 4	36.69 ± 2.47	35.15 ± 2.42			
	Week 6	36.98 ± 2.24	35.29 ± 2.77			
	Week 12	36.70 ± 1.99	35.46 ± 1.64			
Double support (% cycle)	Baseline	26.99 ± 4.20	31.57 ± 8.19	0.908	0.157	0.456
	Week 2	26.77 ± 3.34	28.87 ± 4.70			
	Week 4	26.40 ± 3.86	28.93 ± 3.81			
	Week 6	26.37 ± 3.78	28.44 ± 3.56			
	Week 12	26.66 ± 3.48	28.25 ± 2.84			
Continued						

Variable	Time	Intervention group (n = 23)	Control group (n = 21)	Main effect of time (p)	Main effect of group (p)	Group x Time (p)
		Mean ± SD	Mean ± SD			
Peak angular velocity	**Baseline**	367.94 ± 62.18	335.05 ± 75.32	0.979	0.312	0.409
	Week 2	366.05 ± 42.97	343.34 ± 61.56			
	Week 4	377.45 ± 45.49	348.36 ± 59.68			
	Week 6	371.61 ± 50.37	367.66 ± 49.04			
	Week 12	373.88 ± 55.25	365.98 ± 46.42			
Heel-strike pitch angle	**Baseline**	22.32 ± 3.86	19.33 ± 4.52	0.506	**0.008**	0.513
	Week 2	23.69 ± 3.46	20.50 ± 5.06			
	Week 4	22.48 ± 2.83	19.41 ± 4.43			
	Week 6	23.12 ± 2.85	21.59 ± 3.90			
	Week 12	23.41 ± 3.13	20.40 ± 2.90			
Toe-off pitch angle	**Baseline**	-66.69 ± 7.89	-62.86 ± 9.64	0.878	0.460	**0.004**
	Week 2	-64.93 ± 7.22	-63.56 ± 8.46			
	Week 4	-67.65 ± 8.56	-61.80 ± 8.75			
	Week 6	-66.79 ± 7.36	-65.54 ± 7.64			
	Week 12	-65.84 ± 8.18	-66.32 ± 6.69			
Maximum heel clearance (m)	**Baseline**	0.26 ± 0.02	0.25 ± 0.05	0.335	0.461	0.932
	Week 2	0.25 ± 0.02	0.25 ± 0.05			
	Week 4	0.26 ± 0.02	0.25 ± 0.05			
	Week 6	0.26 ± 0.03	0.25 ± 0.04			
	Week 12	0.025 ± 0.02	0.025 ± 0.02			
Minimum toe clearance (m)	**Baseline**	0.02 ± 0.01	0.02 ± 0.01	0.744	0.220	0.719
	Week 2	0.02 ± 0.01	0.03 ± 0.01			
	Week 4	0.02 ± 0.01	0.03 ± 0.01			
	Week 6	0.02 ± 0.01	0.03 ± 0.01			
	Week 12	0.02 ± 0.01	0.02± 0.01			

SPPB = Short Physical Performance Battery

Patients’ global impression of change

Figure 6.5 illustrates the patients’ global impression of change in the intervention and control groups at each follow-up assessment. Between-group comparisons for global impression of change were significant at each follow-up (week 2: p = 0.004 ; week 4: p = 0.004 ; week 6: p = 0.003 ; week 12 p = 0.028) with the majority of participants in the intervention reported an improvement in their condition (defined as “very much better”, “much better” or “slightly better”), while the majority of participants in the control group reported no change or worsening.

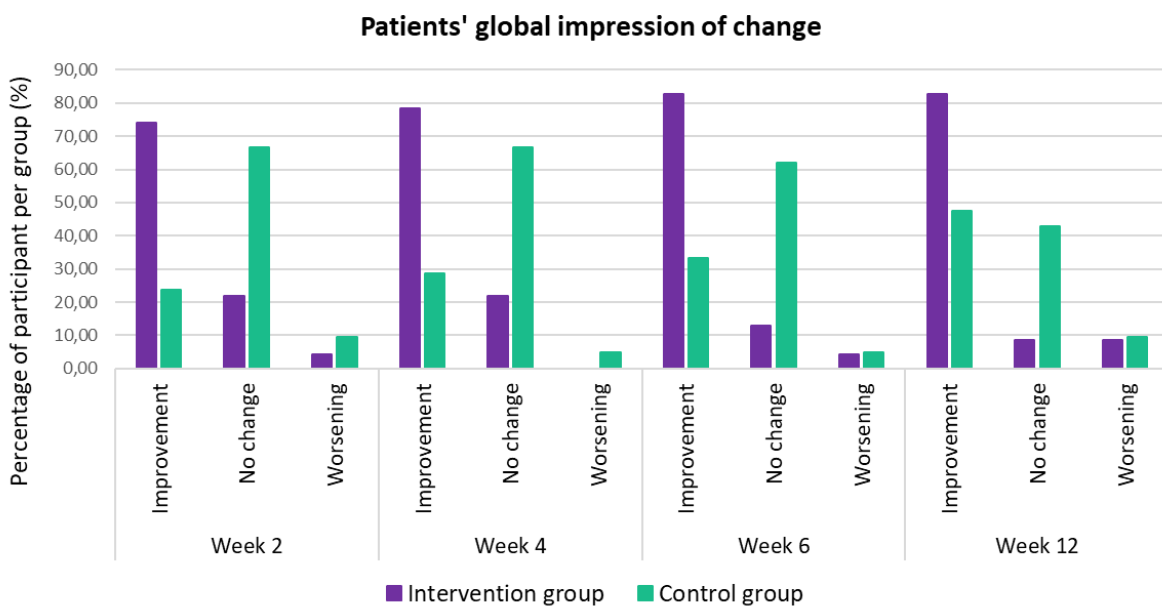

Figure 6.5 - Patients’ global impression of change in both groups (intervention and control) at each follow-up meeting

Deviation from the original protocol

This RCT had one deviation from the originally published protocol. Since not all participants in the intervention group were comfortable with digital technologies or had access to them at home, three participants completed the supervised sessions exclusively in person. All other participants completed the supervised sessions as originally designed.

Clinical significance

After 6 weeks, participants in the intervention group were able to walk 246.09 ± 474.46 m more than at baseline before being forced to stop due to symptoms. This difference continued to increase at 12 weeks, with a mean difference of 384.09 ± 528.17 m. For participants in the control group, the mean differences in total walking distance were 71.04 ± 290.86 m after 6 weeks and 104.24 ± 280.21 m after 12 weeks. Although participants in the intervention group improved their total walking distance after 6 weeks, they reached the previously reported MCID for the SPWT (319 and 376 m)(Carlesso et al., 2021) only after 12 weeks. The between-group differences adjusted for weight after 6 weeks corresponded to a large effect size for walking time to first symptoms (+ 344.79 sec), total walking time (+ 451.55 sec), and total walking distance (+488.33 m), and to a medium effect size for walking distance to first symptoms (+ 419.63 m). The lack of a superior effect of combining exercise and education after the 6-week intervention may be explained by the fact that participants used different strategies to try to walk longer, but not necessarily farther. Indeed, we observed that some participants reduced their walking speed when they experienced higher leg pain intensity prior to the start of the SWPT. They were then able to walk for a longer time, but not further. This strategy is hypothesised to be used in daily life by individuals with LSS causing NC when they must complete a task that requires walking a known distance, such as going to the grocery store.

For the PROMS, the within group differences were clinically significant for decreased LSS-related disability (-6.57 points)(Carlesso et al., 2021) and anxiety (-1.82 points). The MCID was based on previously reported values for individuals with knee or hip osteoarthritis, which range from 1.4 to 4.4 points (de Filippis et al., 2024). To the best of our knowledge, no MCID has been previously determined for self-efficacy as measured by the Chronic Pain Self-Efficacy Scale or its French-Canadian version.

DISCUSSION

The aim of the present study was to evaluate the effectiveness of a 6-week rehabilitation program combining education and exercise on walking capacity in individuals with LSS causing NC. As it was hypothesized, the 6-week rehabilitation program combining education and exercise had a superior effect on walking capacity (time to first symptoms, total walking time and walking distance to first symptoms) than education alone and this effect was sustained at 12 weeks. However, the 6-week rehabilitation program did not have a superior effect on total walking distance compared to education alone. Regarding secondary outcome measures, the 6-week rehabilitation program had a superior effect on LSS-related disability, self-efficacy, and anxiety than education alone. There was no superior effect on back and leg pain intensity, depression, lower extremity physical function and balance, or gait pattern characteristics, except for the toe-off pitch angle, which favored the intervention group.

Rehabilitation program

Recent consensus and guidelines on the management of LSS provide information about the safety and effectiveness of conservative treatments including exercise (Bussières et al., 2021; Comer et al., 2022; Maurizio Fornari et al., 2020; Kawakami et al., 2023; Rousing et al., 2019). Our findings regarding the improvement in walking capacity align with recent studies on rehabilitation interventions for individuals with LSS causing NC that include exercise or education in their multimodal treatment plans (Ammendolia et al., 2018; M. Minetama et al., 2019; Schneider et al., 2019; Williamson et al., 2022). However, most previous RCTs that included exercise also included passive treatments, such as manual therapy. A recent systematic review reported that manual therapy alone is no better than a waitlist, however, the combination of manual therapy and exercise provides a superior and clinically important improvement in symptoms and function compared to medical care and community-based group exercise in the short-term. The combination of manual therapy, exercise, and education has also been shown to provide a significantly superior improvement in walking capacity compared to self-directed home exercise (Ammendolia et al., 2022). The use of multimodal interventions is relevant to improve clinical outcomes related to LSS causing NC, such as symptoms or walking capacity. However, the integration of passive treatments in the treatment plan often requires regular clinical visits, increasing the time and financial demands on individuals compared to exercise (Kawakami et al., 2023). Unlike passive treatment options, approaches centered on exercise and education alone aim to provide individuals with self-management tools for symptoms relief and functional improvement (Hutting et al., 2019). These strategies promote long-term adherence by encouraging exercise that can be performed independently, empowering individuals to manage their symptoms and reducing the need for continuous clinician involvement. In addition, providing a structured yet home-compatible program can help participants to continue to perform exercise at home, which may contribute to sustained engagement and self-management beyond the study period. It is hypothesized that while manual therapy can provide immediate symptoms relief, exercise- and education-based interventions enable individuals to take a more active role in managing their condition, making these approaches more sustainable for those seeking independence in symptom management. In a previous study, individuals with LSS causing NC expressed the need to find ways to improve their walking capacity, despite their inability to alleviate the pain associated with NC (Lyle et al., 2017). It is hypothesized that exercise and education can partially address this need, as they are tools that individuals with LSS can use in their daily lives at home, helping them to better organize their activities. Overall, programs that provide individualized sessions including tailored exercise for LSS-related impairments and limitations, as well as practical tips on self-management strategies, have been well-received by individuals diagnosed with LSS causing NC (Bove et al., 2018).

Exercise

Our study included traditional exercise components, such as aerobic exercises (especially cycling), muscle strengthening, control exercises, and stretches, which are commonly reported in RCT aimed at improving walking capacity, reducing disability, or alleviating pain in individuals with LSS causing NC (Ammendolia et al., 2022; Comer et al., 2024; Jacobi et al., 2021; Marchand et al., 2021; Schneider et al., 2019). This is, to our knowledge, the first study to include both static and dynamic balance exercises, addressing a gap identified in a recent systematic review (Comer et al., 2024). The exercise dosage in our study (three times per week for six weeks) and the level of supervision align with prior research (Ammendolia et al., 2018; Minetama et al., 2019; Schneider et al., 2019) and reflect current evidence for other musculoskeletal conditions, which recommend supervised exercise at least twice a week to achieve meaningful functional improvements (Young et al., 2018).

Education

Educational advice has been reported in previous studies as a part of the conservative treatment plan for managing LSS causing NC (Ammendolia et al., 2018; Schneider et al., 2019; Williamson et al., 2022). However, most authors fail to detail the exact content of the education plan and its delivery. In our study, the education sessions were offered face-to-face and were detailed regarding both content and delivery procedures, allowing for a better replication of the educational component of the rehabilitation plan. In addition, the education was delivered by the main researcher using standardized content for each session.

Strengths and limitations

This study presents several strengths. First, the exercises included in the rehabilitation program were carefully tailored to each participant, ensuring that they were safe, feasible, and progressively challenging. The sessions were supervised by certified kinesiologists, who customized the difficulty level of exercises, allowing for incremental adjustments based on individual capabilities. This personalized approach likely contributed to the program's adherence allowing participants to engage safely and meaningfully based on their physical limitations and strengths. Second, a portion of the training sessions was conducted at home through online platforms, enabling participants to engage in exercise without the constraints related to travel and time required for face-to-face meetings. This home-based component likely improved adherence by accommodating participants who may have difficulties attending in-person sessions regularly. Third, the study included individuals with various symptoms severity and symptoms characteristics related to primary central LSS with NC. By encompassing a wide range of functional impairments and symptom profiles, the trial sample reflects real-world clinical diversity, enhancing the external validity of the findings. Fourth, this RCT is the first, to our knowledge, to monitored gait parameters over time. The use of inertial sensors during the SPWT allowed us to monitor the walking strategies used by participants as they attempted to walk to their maximal capacity, as well as to assess how gait parameters were influenced by the rehabilitation program. In the present study, participants from both groups exhibited slight modifications in their gait parameters over time, although these changes were not statistically significant. This finding suggests that gait deviations may be modifiable with long-term rehabilitation programs, but further studies are needed to explore this hypothesis. Despite several strengths, this study is not without limitations. Although the main researcher was blinded to the group allocation, participants were aware of their assignment, which could introduce bias due to their expectations. In addition, since participants were recruited from specific clinics and through advertisements, there may be a selection bias in the population willing to participate, which could impact generalizability of the results. Indeed, all recruited participants were motivated to follow a 6-week rehabilitation program that included exercises. Another limitation is that we cannot exclude the possibility of general improvement due to natural progression, as we did not include a no-treatment group. Recent studies have shown that the natural course of LSS leads to spontaneous improvement in one-third of individuals, while the condition remains unchanged in another third and worsens in the remaining third (Minamide et al., 2013). Despite fluctuation in back and leg symptoms, walking capacity remains unchanged in nearly half of the individuals with LSS causing NC (P. Wessberg & K. Frennered, 2017). This suggests that the improvement in walking capacity observed in our study may be attributed to the proposed treatment rather than solely to the natural progression of LSS causing NC.

CONCLUSION

Findings from the present study suggest that a 6-week rehabilitation program combining education and exercises had a superior effect on the improvement of walking capacity, as evidenced by increased time to first symptoms, total walking time, and distance walked before the onset of symptoms, compared to education alone and that this improvement persists up to the 12th week. The rehabilitation program also had a positive impact on LSS-related disability, self-efficacy, and anxiety. Despite these improvements, the rehabilitation program did not show a superior effect on total walking distance and no significant differences were observed regarding back and leg pain intensity, depression, lower extremity physical function and balance, or gait pattern characteristics, when compared to education alone. The proposed rehabilitation program could provide individuals with additional tools to self-manage their condition over time. Our findings also indicate that a combined approach of exercise and education offers significant benefits for walking capacity and psychological well-being. Further studies exploring personalized approaches that adapt to individual patients' specific needs (e.g., walking capacity, pain-management, or balance) are needed.

Conflict of interest: There is no conflict of interest.

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Chapitre 7 – Discussion générale

Dans le cadre des travaux réalisés au cours de la thèse, nous avons poursuivi trois objectifs principaux : 1) identifier les facteurs physiques et psychologiques associés au déclin des capacités fonctionnelles des patients ayant un diagnostic de SSL, en s'intéressant plus particulièrement à la marche, 2) caractériser les paramètres de la marche chez ces patients et 3) évaluer l'efficacité d'un programme de réadaptation combinant exercices et éducation pour améliorer leur capacité de marche. Pour répondre à ces objectifs, quatre études ont été réalisées. La première section de cette discussion propose donc une synthèse des principaux résultats des travaux de cette thèse.

Synthèse des principaux résultats

La première étude présentée dans cette thèse a permis, par l'entremise d'une revue intégrative de la littérature incluant 24 études, d'identifier les associations entre, d'une part, les facteurs physiques et psychologiques et, d'autre part, la capacité de marche, la performance lors de tâches fonctionnelles impliquant la locomotion ou les paramètres de la marche. Les résultats principaux issus de cette revue intégrative montrent que les associations entre la capacité de marche et les facteurs physiques et psychologiques sont généralement contradictoires. Quelques associations plus clairement établies ont toutefois émergées de cette revue intégrative. Concernant les facteurs physiques, les résultats montrent une association négative entre, d'une part, différentes composantes de la capacité de marche (p. ex., distance de marche totale) et, d'autre part, certaines mesures relatives à la douleur (p. ex., le nombre d'années avec des douleurs au dos et aux jambes et l'intensité de la douleur aux jambes avant d'effectuer un test de marche), l'incapacité liée à la SSL, l'incapacité lombaire et la surface transversale du canal dural au niveau des vertèbres lombaires L1 et L2. De plus, les résultats de cette revue intégrative montrent une association positive entre la capacité de marche et l'estimation de la distance de marche par les patients. Les résultats indiquent aussi que la performance lors de tâches fonctionnelles est associée à l'incapacité lombaire et à celle des membres supérieurs, à l'endurance des muscles du tronc, à la force, à l'amplitude de mouvement et à la vitesse des membres inférieurs lors d'une tâche de « *leg press* ».

Concernant les paramètres de la marche, les résultats de la revue intégrative indiquent une association négative entre l'incapacité mesurée avec le *Quebec Back Pain Disability Scale* (QBPDS) et la vitesse de marche ainsi qu'une association positive entre l'incapacité mesurée avec le *Japanese Orthopedic Association Back Pain Evaluation Questionnaire* (JOABPED) et la longueur de foulée. Les résultats de la revue intégrative révèlent aussi l'absence de données probantes concernant la relation entre la capacité de marche et les différents paramètres de la marche (généraux, spatio-temporels et de dégagement du pied). Enfin, concernant les facteurs psychologiques, les résultats de la revue intégrative montrent que seules l'anxiété mesurée avec le questionnaire *Pain Anxiety Symptom Scale* (PASS-20) et la sévérité de la dépression mesurée avec le questionnaire *Rasch-based Depression Screener* (DESC) sont associées à la performance dans les tâches fonctionnelles.

La deuxième étude de cette thèse avait pour objectif de décrire et de comparer les paramètres de la marche chez les personnes âgées en fonction de l'âge et du sexe. Les principaux résultats de cette étude indiquent que les paramètres de la marche sont généralement différents chez les personnes âgées de 70 ans et plus lorsque comparés à des personnes âgées de 50 à 69 ans. Cette étude a également permis d'identifier des différences entre les hommes et les femmes pour la majorité des paramètres à la marche. Bien qu'elle n'implique pas d'individus ayant un diagnostic de SSL avec CN, cette étude était essentielle afin de bien comprendre les changements au niveau du patron de marche qui sont attribuables au processus de vieillissement. Les résultats de cette étude ont, par la suite, servi de mesure de références pour l'étude 3.

La troisième étude de cette thèse avait pour objectif d'identifier les différences dans les paramètres généraux, spatiaux, temporaux et de dégagement du pied lors de la marche entre les patients ayant un diagnostic de SSL avec CN et ceux de personnes âgées sans douleur. Les résultats principaux de cette étude montrent que les paramètres généraux, spatiaux et temporaux de la marche des patients ayant un diagnostic de SSL avec CN sont différents de ceux observés chez les personnes âgées sans douleur. Plus précisément, les résultats de cette deuxième étude montrent un cycle de marche plus long, une cadence plus faible, une longueur de pas plus courte et une vitesse de marche plus lente chez les patients ayant un diagnostic de SSL avec CN en comparaison à ce qui a été observé chez les personnes âgées sans douleur. Pour les paramètres temporaux de la marche, les patients ayant un diagnostic de SSL avec CN ont une phase d'appui, une sous-phase de pied à plat et une phase de double support plus longues alors qu'ils présentent des sous-phases de mise en charge et de poussée de même qu'une phase d'oscillation plus courtes. Les résultats montrent aussi que les patients ayant un diagnostic de SSL avec CN ont une vitesse angulaire du pied, un angle d'attaque du talon et un angle de poussée des orteils plus faibles que les personnes âgées sans douleur. Pour les paramètres de dégagement du pied, les résultats montrent que les valeurs maximales de dégagement du talon et les valeurs minimales de dégagement des orteils sont similaires entre les patients ayant un diagnostic de SSL avec CN et les personnes âgées sans douleur.

L'étude quatre avait, quant à elle, l'objectif de décrire le protocole de recherche d'un essai clinique contrôlé et randomisé visant à évaluer l'efficacité d'un programme de réadaptation combinant des exercices et de l'éducation développé pour les patients ayant un diagnostic de SSL avec CN. Ainsi l'étude 3 met de l'avant les choix méthodologiques concernant l'évaluation de la capacité de marche et des mesures de résultats cliniques physiques et psychologiques qui découlent des observations réalisées dans le cadre des études 1 et 2 de cette thèse. Elle jette aussi les bases du contenu d'un programme de réadaptation combinant des exercices et de l'éducation développé pour les patients ayant un diagnostic de SSL avec CN.

Finalement, l'étude cinq présente les résultats préliminaires d'un essai clinique randomisé et contrôlé dont l'objectif était de déterminer l'efficacité du programme de réadaptation proposé dans l'étude quatre pour améliorer la capacité de marche des patients ayant un diagnostic de SSL avec CN. Les résultats préliminaires montrent que le programme de réadaptation proposé combinant des exercices et de l'éducation a un effet supérieur à l'éducation seule pour améliorer la capacité de marche des patients. Plus précisément, le programme de réadaptation permet d'améliorer davantage la capacité de marche qu'un programme d'éducation seul sur une période de 6 semaines et ses effets persistent au moins pendant 6 semaines suivant la fin des interventions (semaine 12). Bien que ce n'ait pas été l'objectif primaire de cette étude, le programme de réadaptation montre aussi une efficacité supérieure à l'éducation seule quant à l'amélioration de l'incapacité, de l'anxiété et du sentiment d'auto-efficacité. Les résultats préliminaires montrent toutefois que le programme n'a pas un effet supérieur à l'éducation seule pour les mesures de résultats cliniques suivantes : l'intensité de la douleur au dos et aux jambes, les paramètres de la marche, la fonction physique des membres inférieurs et l'équilibre ainsi que la dépression.

Les prochaines sections de la discussion permettront de placer les résultats issus des différentes études de cette thèse dans le contexte des connaissances actuelles du domaine. Elles proposeront également un cadre pour la prise en charge de la SSL avec CN, fondé sur l'exercice et l'éducation comme modalités actives de traitement conservateur de la SSL avec CN. Les forces et les limites de la thèse ainsi que les perspectives de recherche seront aussi abordées.

Associations entre les facteurs physiques et psychologiques et la capacité de marche : un besoin de standardisation des mesures

Étudier les associations entre la capacité de marche et les facteurs physiques et psychologiques chez les patients ayant un diagnostic de SSL avec CN revêt un intérêt scientifique et clinique important comme en témoigne les 24 articles inclus dans la revue intégrative (étude 1 – voir Chapitre 2) de cette thèse. Bien que certaines des études incluses ne se soient pas intéressées directement à la capacité de marche, mais plutôt à la marche dans un contexte de tâche fonctionnelle, ces études ont permis de constater que les associations entre la marche et les facteurs physiques et psychologiques des patients ayant un diagnostic de SSL sont complexes. La majorité des associations entre les facteurs physiques (intensité de la douleur, incapacité, distance de marche estimée) et psychologiques (anxiété, dépression, kinésiophobie, qualité de vie) et la capacité de marche identifiées dans la revue intégrative étaient évaluées à l'aide de questionnaires auto-rapportés. L'utilisation de mesures auto-rapportées avec différents outils dans les études incluses pourrait, en partie, expliquer les résultats contradictoires, en raison des variations potentielles des propriétés psychométriques entre les questionnaires utilisés pour mesurer une même mesure de résultat (Chiarotto et al., 2016).

Historiquement, les questionnaires auto-rapportés ont été développés pour le contexte de la recherche et particulièrement pour évaluer l'efficacité de traitements proposés (Health et al., 2006). Ces questionnaires sont toujours utilisés dans le milieu de la recherche, mais leur utilisation s'étend désormais également aux milieux cliniques (Churruca et al., 2021). Bien que l'usage de questionnaires auto-rapportés permette d'intégrer la perspective du patient (Devlin & Appleby, 2010) et de faciliter l'implication du patient dans la prise de décision clinique en le plaçant comme un expert de sa condition (Black, 2013), leur sélection nécessite une réflexion plus approfondie de la part des cliniciens et des chercheurs qui souhaitent les utiliser. En effet, certains questionnaires auto-rapportés sont plutôt génériques alors que d'autres ont été développés pour une condition spécifique (Churruca et al., 2021). Les questionnaires auto-rapportés spécifiquement développés pour une condition de santé présentent généralement une plus grande validité et crédibilité ainsi qu'une sensibilité accrue aux changements pouvant être observés chez le patient (Black, 2013). Ils sont souvent donc plus appropriés que les questionnaires auto-rapportés plus généraux (Churruca et al., 2021).

Les résultats de la revue intégrative montrent bien l'usage de différents questionnaires génériques et spécifiques pour évaluer une même mesure de résultat clinique (p. ex., l'incapacité qui est un facteur physique). La revue intégrative indique, par exemple, que les outils les plus fréquemment utilisés pour évaluer l'incapacité sont le *Oswestry Disability Index* (ODI), le *Swiss Spinal Stenosis Questionnaire* (SSSQ), aussi connu sous le nom *du Zurich Claudication Questionnaire* (ZCQ), et le *Quebec Back Pain Disability Scale* (QBPDS). Bien que les questionnaires ODI et QBPDS soient des questionnaires valides et fiables pour mesurer l'incapacité (Cleland et al., 2012; Comer et al., 2011; Hicks & Manal, 2009; Marchand et al., 2019; Yvanes-Thomas et al., 2002), seul le SSSQ a été spécifiquement développé pour fournir de l'information quant aux symptômes, à la fonction et même la satisfaction des soins chirurgicaux chez les patients ayant un diagnostic de SSL avec CN. Le SSSQ présente un niveau de sensibilité au changement (*responsiveness*) adéquat et permet d'évaluer l'efficacité d'un traitement non chirurgical chez les patients ayant un diagnostic de SSL tout en discriminant les répondants des non-répondants suite à des soins conservateurs (Carlesso et al., 2021).

Au-delà de la qualité psychométrique des différents questionnaires, l'évaluation de la qualité méthodologique des études portant sur les mesures auto-rapportées semble occuper une place de plus en plus importante comme en témoigne l'initiative *COnsensus-based Standards for the selection of health Measurement Instruments* (COSMIN). L'initiative COSMIN a pour objectif d'améliorer la sélection des instruments de mesure de résultats cliniques en élaborant des lignes directrices méthodologiques fondées sur un consensus d'experts internationaux (Mokkink et al., 2016). Ce consensus d'experts a d'ailleurs mis sur pied des outils destinés aux chercheurs permettant d'établir des *Core Outcome Sets* (COS) qui comportent les mesures de résultats cliniques standardisées qui devraient se retrouver minimalement dans les essais cliniques de la population spécifique pour qui le COS est développé. Ce type de consensus existe pour certaines conditions musculosquelettiques dont les douleurs lombaires non spécifiques (Chiarotto et al., 2015) et les douleurs lombaires chroniques (Dutmer et al., 2019), mais aucun consensus ne semble encore avoir été établi pour la SSL.

Ainsi, à la lumière des résultats de la revue intégrative, le niveau d'activité physique, l'incapacité et l'intensité de la douleur ainsi que l'anxiété, la dépression, la qualité de vie et la kinésiophobie nous apparaissent comme les mesures de résultats cliniques les plus pertinentes pour la SSL. Bien que l'identification de COS n'ait pas fait partie intégrante de l'objectif de cette première étude, la revue intégrative nous a permis de guider les choix méthodologiques concernant l'évaluation des mesures de résultats cliniques de nature physique et psychologique pour les études 2 à 4 de cette thèse.

Impact de la SSL avec CN sur les paramètres biomécaniques de la marche

Considérant l'absence de données probantes concernant les associations entre les paramètres biomécaniques de la marche et la capacité de marche identifiée dans l'étude 1 (revue intégrative), nous avons jugé essentiel d'évaluer les paramètres de la marche des patients ayant un diagnostic de SSL avec CN. Pour mieux caractériser ces paramètres chez les patients ayant un diagnostic de SSL avec CN, il était essentiel de d'abord comprendre les changements au niveau des paramètres à la marche chez les personnes âgées sans douleur (deuxième étude de cette thèse) pour ensuite comparer les paramètres des personnes âgées sans douleur à celles des patients ayant un diagnostic de SSL avec CN. Les résultats de la deuxième étude ont permis d'identifier des différences entre les groupes d'individus âgés de 50 à 69 ans et les individus âgés de 70 ans et plus pour l'ensemble des paramètres à la marche à l'exception de la durée du cycle de marche, la cadence et des phases d'appui, d'oscillation et de double support. Ces résultats sont cohérents avec les données probantes existantes qui montrent que les changements sont généralement observables à partir d'un âge plus avancé (Beauchet et al., 2017; Hollman et al., 2011; McKay et al., 2017). Pour sa part, les résultats de la troisième étude de cette thèse (étude comparative) mettent en lumière les différences et les similitudes observées entre les paramètres de la marche des patients ayant un diagnostic de SSL avec CN et un groupe de personnes âgées sans douleur à la marche.

La vitesse de marche, la longueur de foulée et la cadence sont des paramètres biomécaniques généraux de la marche qui sont régulièrement mesurés dans les études portant sur les conditions de santé affectant la marche (Ornetti et al., 2010; Pirker & Katzenschlager, 2017). Pour la SSL, ce sont des facteurs objectifs communément mesurés pour comprendre les limitations fonctionnelles (Wang et al., 2022). D'ailleurs, des résultats importants de la troisième étude de cette thèse, c'est-à-dire, la présence d'une vitesse de marche plus lente et d'une longueur de foulée plus courte chez les patients ayant un diagnostic de SSL que chez les personnes âgées sans douleur sont cohérents avec les données probantes actuelles. En effet, une revue de la littérature récente, incluant des études qui ont mesuré les paramètres de la marche à l'aide de technologies portables, rapporte que les patients ayant une SSL présentent une vitesse de marche plus lente et une longueur de foulée plus courte en période préchirurgicale que les participants du groupe témoin auxquels ils ont été comparés (Chakravorty et al., 2019). Un autre étude réalisée en laboratoire rapporte aussi une vitesse de marche plus lente et une longueur de foulée plus courte chez les patients ayant un diagnostic de SSL avec CN lorsque comparés à un groupe témoin (Kuwahara et al., 2016).

En ce qui concerne la cadence, les résultats de la troisième étude de cette thèse montrent une cadence plus basse chez les patients ayant un diagnostic de SSL. Une revue systématique récente rapporte, quant à elle, des résultats plutôt contradictoires concernant les différences observées pour la cadence entre les patients SSL et les individus sains (Chakravorty et al., 2019). En effet, les résultats de la première étude incluse dans la revue systématique montrent une cadence similaire entre les deux groupes (Sun et al., 2018) alors que les résultats de la seconde montrent une cadence plus basse chez les patients ayant un diagnostic de SSL (Loske et al., 2018). La nature du test de marche utilisé dans la première étude (courte distance de 16 mètres), peut potentiellement expliquer le fait que la cadence était similaire entre les deux groupes de participants (patients SSL et individus sains) puisque les symptômes douloureux peuvent mettre un certain temps à se manifester chez les patients. D'autres études ayant comparé la cadence entre les patients SSL et des individus sains en utilisant des techniques d'analyse de la marche différentes des capteurs inertiels (p. ex., analyse manuelle de vidéos et utilisation d'un système de caméra Vicon) révèlent aussi une cadence plus basse chez les patients ayant un diagnostic de SSL en comparaison à des individus sains (Kuwahara et al., 2016; Perring et al., 2020).

Au regard des données probantes actuelles, les différences observées pour la vitesse de marche, la longueur de foulée et la cadence dans notre étude sont semblables à celles observées chez les personnes atteintes d'autres conditions musculosquelettiques comme l'arthrose symptomatique de la hanche et du genou (Boekesteijn et al., 2022; Constantinou et al., 2014; Mills et al., 2013). Bien que ces conditions ne partagent pas les mêmes mécanismes douloureux (douleur inflammatoire dans le cas de l'arthrose du genou et de la hanche et douleur neurogène dans la SSL), ces deux conditions représentent des causes fréquentes d'incapacité chez les personnes âgées en raison de douleur aux jambes (Ishimoto et al., 2012; Vina & Kwoh, 2018; Yelin, 2003). La vitesse de marche plus lente chez les individus ayant de l'arthrose au genou serait une stratégie utilisée pour diminuer la charge sur le genou douloureux (Mundermann et al., 2004). Les différences observées entre les patients ayant un diagnostic de SSL avec CN et les personnes sans douleur notamment en ce qui concerne la vitesse de marche pourraient donc refléter une stratégie mise en place par les patients pour soulager leurs symptômes tout en préservant leur capacité à marcher. Des études de laboratoire impliquant des analyses de la cinétique et de la cinématique lors de la marche devront cependant être réalisées pour valider cette hypothèse.

Les résultats de la troisième étude de la thèse concernant les différences observées entre les patients ayant un diagnostic de SSL avec CN pour l'ensemble des paramètres temporaux et spatiaux contribuent à l'ajout de nouvelles informations sur la marche des patients ayant un diagnostic de SSL avec CN. En effet, cette étude est, à notre connaissance, la première étude à mesurer et comparer les paramètres temporaux et spatiaux de la sorte. Nos résultats permettent donc de combler partiellement le manque de données probantes soulevé dans la revue systématique de Chakrovorty et ses collègues concernant les paramètres spatiaux et temporaux

(Chakravorty et al., 2019). Dans une étude d'Odonkor et ses collègues publiée en 2020, les auteurs se sont intéressés à ces paramètres de marche afin d'identifier lesquels pouvaient être utilisés pour discriminer les patients avec SSL des individus sains (Odonkor et al., 2020). Les résultats de l'étude montrent que la sous-phase de pied à plat fait partie des paramètres de la marche qui permettent de mieux discriminer les deux populations, et ce, sans regard à la distance et la durée du test de marche (Odonkor et al., 2020). Pour leur part, les paramètres spatiaux auraient une capacité discriminante plus faible (Odonkor et al., 2020). Dans le cycle de la marche, la sous-phase de pied à plat survient lorsque la jambe est en contact complet avec le sol et fait partie de la phase d'appui. Une prolongation de cette sous-phase survient conjointement avec la prolongation de la phase d'appui qui à son tour s'accompagne généralement de la prolongation de la phase de double support. En prolongeant la phase de double support, les patients peuvent mieux répartir la charge sur les deux jambes limitant ainsi la charge sur le côté le plus douloureux (Chen et al., 2003) en plus d'améliorer leur stabilité (Li et al., 2021). Ainsi, les différences observées dans les paramètres temporaux et spatiaux entre les patients SSL avec CN et les personnes âgées sans douleur de même que la capacité discriminante de la sous-phase de pied à plat identifiée dans l'étude d'Odonkor suggèrent l'adoption de stratégies compensatoires de la part des patients afin de limiter la douleur à la marche attribuable à la condition de SSL avec CN. Encore une fois, cette hypothèse reste à valider.

À la lumière des résultats obtenus dans la troisième étude de cette thèse et des données probantes existantes sur les paramètres de la marche chez les patients ayant un diagnostic de SSL avec CN, les différences observées permettent d'émettre l'hypothèse que des stratégies compensatoires à la marche soient adoptées par les patients afin de limiter les symptômes douloureux engendrés par la condition de SSL avec CN et améliorer leur stabilité à la marche. Cependant, des études longitudinales réalisées auprès de cohortes de personnes âgées incluant des évaluations fréquentes des paramètres de la marche seront nécessaires pour confirmer cette hypothèse et identifier les stratégies utilisées par les patients. Il serait également intéressant de comparer les stratégies utilisées en fonction de l'intensité des symptômes et du niveau d'incapacité rapportée par les patients afin de voir si des sous-groupes de patients peuvent être identifiés. L'identification des stratégies utilisées et des sous-groupes de patients pourrait contribuer à améliorer la trajectoire de soins en proposant des interventions conservatrices mieux ciblées et adaptées aux altérations présentes chez les patients.

Approche combinée en réadaptation pour la SSL avec CN : efficacité d'un programme de 6 semaines sur la capacité de marche

Actuellement, les options thérapeutiques conservatrices sont généralement les premières options proposées aux patients ayant un diagnostic de SSL (Bussières et al., 2021). Devant la diversité des options thérapeutiques conservatrices pour la SSL avec CN et le manque d'évidence sur leur efficacité (Ammendolia et al., 2022; Bussières et al., 2021; Mamoru Kawakami et al., 2023), l'algorithme publié en 2022 sur la trajectoire des soins (Comer et al., 2022) souligne la nécessité de programmes de réadaptation efficaces intégrant des exercices et de l'éducation.
L'étude cinq de cette thèse s'inscrit dans cette volonté de tester l'efficacité d'un programme dédié aux patients ayant un diagnostic de SSL avec CN qui combine des exercices et de l'éducation pour améliorer la capacité de marche. Les résultats préliminaires issus de cette étude montrent qu'un programme de réadaptation combinant des exercices et de l'éducation permet d'améliorer davantage la capacité de marche qu'un programme d'éducation seul sur une période de six semaines et que les effets persistent au moins pendant six semaines après l'intervention (jusqu'à la semaine 12). Cet effet positif est observé sur le temps de marche avant l'apparition des symptômes, le temps total de marche et sur la distance de marche avant l'apparition des symptômes. Bien que cet effet statistiquement significatif n'ait pas été observé pour la distance totale de marche, les patients du groupe d'intervention ayant reçu les exercices et l'éducation ont tout de même amélioré leur distance de marche totale (différence moyenne de 384,09 ± 474,46 mètres), atteignant ainsi un changement cliniquement significatif pour cette mesure (Carlesso et al., 2021) après 12 semaines.

L'étude cinq contribue à améliorer les connaissances quant à l'efficacité d'un programme de réadaptation combinant des exercices et de l'éducation notamment en étant, à notre connaissance, la toute première étude à tester l'efficacité de la combinaison des exercices et de l'éducation en comparaison à l'éducation seule et la toute première à intégrer des séances d'exercices supervisées selon un mode hybride (présentiel et à distance) ainsi que des exercices adaptés et individualisés (difficulté, séries, répétitions) pour le patient. En effet, selon la mise à jour des données probantes portant sur les traitements non chirurgicaux présentés dans la revue systématique d'Ammendolia et ses collègues publiée en 2022, la plupart des études contrôlées randomisées comprenant des exercices impliquaient aussi des modalités passives de traitement comme la thérapie manuelle, l'acupuncture, la stimulation nerveuse électrique transcutanée (TENS) ou des ultrasons (Carlo Ammendolia et al., 2022). Une seule étude a comparé l'efficacité des exercices et de l'éducation à l'efficacité de la décompression et a conclu que les deux interventions possèdent des effets similaires à long terme (2 ans) pour les mesures de résultats cliniques suivantes : qualité de vie et incapacité lombaire (Delitto et al., 2015). Une autre étude s'est intéressée à l'efficacité des exercices, mais cette fois uniquement chez les patients en attente d'une chirurgie élective (Marchand et al., 2021). De plus, les modalités d'exercices sont très hétérogènes dans les études actuelles allant des exercices réalisés en groupe dans la communauté (Schneider et al., 2019) aux exercices à la maison (Ammendolia et al., 2018; Minetama et al., 2019) en passant par les exercices supervisés (Ammendolia et al., 2018; Marchand et al., 2021; Minetama et al., 2019; Schneider et al., 2019).

Les résultats de l'étude cinq répondent également en partie aux besoins identifiés par les patients quant à l'éducation et aux stratégies d'autogestion des symptômes. En effet, une étude qualitative menée par Lynch et ses collègues révèle que les patients ayant un diagnostic de SSL sont en quête d'informations leur permettant de mieux comprendre la condition, son évolution et les options thérapeutiques existantes (Lynch et al., 2018). L'étude mentionne aussi que les patients ont tendance à utiliser et à interpréter les informations trouvées sur internet et dans les médias (Lynch et al., 2018). L'usage d'un programme standardisé tel qu'utilisé dans le cadre de notre étude pourrait permettre aux patients de combler ce besoin d'information et assure la justesse de l'information transmise aux patients tout en assurant leur participation active dans le processus de réadaptation.

Au regard des résultats de cette thèse, l'éducation et les exercices semblent donc des éléments clés qui favorisent l'autogestion des symptômes et l'amélioration de la capacité de marche des patients ayant un diagnostic de SSL avec CN.

Évolution des facteurs physiques et psychologiques dans le cadre d'un programme de réadaptation combinant des exercices et de l'éducation

Considérant les paramètres physiques et psychologiques rapportés dans la revue intégrative (étude 1) et les résultats issus de l'étude comparative (étude 3), il apparaissait essentiel de suivre l'évolution des facteurs physiques et psychologiques en parallèle à l'évolution de la capacité de marche des patients dans un contexte de réadaptation. Bien que ce n'ait pas été l'objectif primaire de l'étude cinq, les résultats préliminaires montrent que le programme combinant des exercices et de l'éducation permet l'amélioration de l'incapacité ainsi que de l'anxiété et du sentiment d'auto-efficacité. Ces résultats sont cohérents avec les données probantes spécifiques à la SSL mais aussi avec celles d'autres conditions chroniques. En effet, la prise en charge conservatrice par l'exercice est bien connue pour son effet positif sur la fonction physique, la réduction de l'anxiété et l'amélioration du sentiment d'auto-efficacité (Booth et al., 2017). L'usage d'éducation et d'exercices permet au patient de développer une alliance thérapeutique avec son intervenant pour ainsi mieux adhérer au traitement proposé (Booth et al., 2017; Ferreira et al., 2013). Les améliorations observées dans les mesures cliniques d'incapacité, d'anxiété et d'auto-efficacité, parallèlement à l'augmentation de la capacité de marche, suggèrent une possible relation entre les divers facteurs physiques et psychologiques et la capacité de marche. La présence et la nature de ces relations potentielles demeurent toutefois à confirmer.

Le programme de réadaptation n'a pas eu d'effet sur le niveau fonctionnel du membre inférieur ni sur l'équilibre, tels que mesurés par le *Short Physical Performance Battery* (SPPB), qui évalue également la fragilité physique. Sachant que la prévalence de la fragilité est plus élevée chez les patients ayant un diagnostic de SSL que chez les personnes âgées en général (Kim et al., 2019), cette mesure de fragilité semblait pertinente pour l'étude cinq. Toutefois, les participants inclus dans le groupe d'intervention de l'étude cinq ont obtenu un score initial indiquant une performance moyenne au SPPB et donc que de légers signes de fragilité physique (Ramírez-Vélez et al., 2021). La mesure de fragilité demeure cependant pertinente pour les patients qui ont une incapacité plus sévère (p. ex., candidats à la chirurgie). En effet, les résultats d'une étude récente indiquent que près de 20% et 70% des patients ayant un diagnostic de SSL et étant candidats pour la chirurgie sont respectivement classés dans la catégorie fragile ou préfragile (Sugimoto et al., 2024).

Approches innovantes en réadaptation : technologies portables et plateformes de télécommunication

Les travaux de cette thèse se démarquent grâce au recours à deux types de technologies récentes soient les technologies portables (capteurs inertiels) et les plateformes de télécommunication (p. ex., ZOOM). L'usage des technologies portables comme les capteurs inertiels permet l'évaluation de la marche dans un contexte plus près de la réalité quotidienne des patients (Benson et al., 2018; Brodie et al., 2016) tout en limitant les contraintes physiques pouvant nuire au mouvement (Byun et al., 2019; Muro-De-La-Herran et al., 2014; Regterschot et al., 2021). L'usage des plateformes de télécommunication pour la réalisation de séances d'exercices supervisés s'avère un point saillant de l'étude cinq comme en témoigne le taux de participation aux séances supervisées individuelles (86,96%). Selon les données probantes existantes, l'usage de la téléréadaptation est généralement bien acceptée, et ce, pour bon nombre de conditions de santé (p. ex., troubles musculosquelettiques, cardiaques ou respiratoires) (Bettger et al., 2020; Hansen et al., 2020; Hwang et al., 2017; Peng et al., 2018; Russell et al., 2011; Zhang et al., 2022). De plus, les résultats d'une étude récente indiquent que l'âge n'est pas un obstacle à l'utilisation de la téléréadaptation (Crotty et al., 2014). Dans un contexte clinique, l'utilisation des plateformes de télécommunication présente de nombreux avantages, tant pour les patients nécessitant des soins que pour les professionnels de santé qui dispensent les soins. Pour les patients ayant des limitations fonctionnelles, comme ceux atteints de SSL avec CN, les séances d'exercices supervisées à domicile leur permettent de rester dans un environnement familier et pour ceux vivant dans des régions éloignées des centres de soins, ces séances d'exercices à distance réduisent les contraintes physiques et les coûts financiers associés aux déplacements (Amin et al., 2020). Cette barrière de la distance entre le domicile et le lieu où les soins sont offerts a d'ailleurs été soulevée dans une étude précédente par les patients ayant un diagnostic de SSL (A. M. Bove et al., 2018). Finalement, en permettant aux patients de suivre des séances dans l'intimité de leur domicile, la téléréadaptation contribue aussi à la réduction des barrières psychologiques liées à l'activité physique et encourage une approche proactive de la santé (Bradford et al., 2016).

Limites

Limites des études recensées

Outre la grande variabilité dans les outils de mesures présentées dans la revue intégrative, d'autres éléments peuvent expliquer les résultats contradictoires répertoriés. Le premier élément à considérer est l'hétérogénéité des définitions présentées pour la SSL et la CN à travers les différentes études incluses. Certaines études présentaient des critères d'inclusion clairs et stricts alors que pour d'autres ces critères étaient peu ou pas définis. De plus, il est généralement difficile de restreindre les critères d'inclusion à la SSL centrale uniquement. La colonne vertébrale subissant plusieurs changements anatomiques en raison de l'arthrose, plusieurs individus peuvent présenter une combinaison de plusieurs types de SSL (p. ex., SSL centrale et SSL foraminale ou SSL centrale et SSL latérale). Généralement, lorsque la localisation exacte de la SSL n'est pas mentionnée, les auteurs des revues systématiques tiennent pour acquis que le type de SSL évalué est la SSL centrale (Jensen et al., 2020). Le deuxième élément à considérer est l'hétérogénéité des tests utilisés pour mesure la capacité de marche. Par exemple, certains auteurs ont évalué la capacité de marche sur tapis roulant à l'aide de test comme le *Motorized Treadmill Test* (MTT) alors que d'autres l'ont mesurée au sol avec le *Self-Paced Walking Test* (SPWT). Bien que les deux tests de marche corrèlent bien avec les mesures de capacité de marche auto-rapportées, la vitesse de marche sur tapis roulant est généralement plus lente lors de l'utilisation d'un test comme le MTT que celle observée avec un test comme le SPWT, même si la vitesse est choisie par le patient dans les deux cas. Cette diminution de la vitesse suggère que pour une même durée de marche, les patients auront parcouru une distance de marche plus courte avant l'apparition des symptômes (Rainville et al., 2012). L'hypothèse émise par les auteurs pour expliquer cette différence de vitesse est le fait que les patients pourraient manquer de familiarisation avec le tapis roulant.

Limites des travaux de la thèse

Limites des travaux de la thèse

Malgré les efforts réalisés pour mieux définir les critères d'inclusion des travaux expérimentaux présentés dans cette thèse, une certaine hétérogénéité des patients persiste. Plusieurs des patients inclus dans l'un ou l'autre des projets de cette thèse présentaient une combinaison de types de SSL. La présence d'une telle combinaison est commune et peut complexifier la recherche sur l'efficacité d'un traitement ciblé pour un type de SSL donné. Ce type de patient représente cependant une proportion non négligeable des cas de SSL et leur exclusion aurait, au contraire, pu engendrer un biais de sélection. En 2022, une équipe de chercheurs a identifié trois phénotypes basés sur les symptômes cliniques des patients et a développé un algorithme de prise en charge de la condition. Les trois phénotypes se rapportent aux A) symptômes de CN, B) aux symptômes sensoriels et d'équilibre associés à la CN et C) symptômes douloureux radiculaires unilatéraux (Comer et al., 2022). Bien que cet algorithme ait été publié après la mise en place des études 2 à cinq, celui-ci vient tout de même soutenir les choix méthodologiques réalisés concernant 1) l'inclusion de participants pouvant avoir un diagnostic de SSL qui implique minimalement la SSL centrale et la présence de CN et 2) les options thérapeutiques choisies, soit l'utilisation d'exercices et d'éducation.

Une autre limite méthodologique de cette thèse est l'absence de standardisation des chaussures dans les études 2 et 4 qui pourrait engendrer un biais de confusion. En effet, les participants inclus dans ces projets ont eu comme consigne de porter leurs propres chaussures de sport fermées et confortables pour l'évaluation de la marche. Bien que des chaussures standardisées auraient pu limiter certaines variables confondantes (p. ex., flexibilité de la semelle, usure et poids de la chaussure), l'utilisation des chaussures habituelles permet une évaluation plus représentative de leur capacité de marche au quotidien. Par ailleurs, des chaussures standardisées, aux caractéristiques parfois différentes (p. ex., hauteur de semelle, rigidité, adhérence), peuvent modifier la biomécanique de la marche (Hong et al., 2005; Menant et al., 2009; Thies et al., 2015). Dans les études expérimentales de cette thèse, les participants ont tous effectué les évaluations avec la même chaussure au pied assurant ainsi la cohérence intra-individuelle et facilitant la détection de changements au fil du temps.

Finalement, il aurait été intéressant de diviser l'analyse des paramètres de la marche présentée dans la quatrième étude de cette thèse en deux sections : avant et après l'apparition des symptômes. En effet, les analyses préliminaires de ces paramètres ont plutôt été réalisées sur toute la durée du test de marche. En moyennant ainsi les données, il est impossible de distinguer les changements engendrer par l'apparition ou l'augmentation des symptômes. L'identification de ces changements fournirait des informations précieuses sur les mécanismes compensatoires que les patients mettent en place pour gérer la douleur et les limitations fonctionnelles. Cette limite relevée sera prise en considération lors des analyses finales de ce projet.

Perspectives de recherche

Au regard des résultats issus de cette thèse, plusieurs perspectives de recherche méritent d'être explorées afin d'améliorer les connaissances sur la condition et d'améliorer la prise en charge des patients ayant un diagnostic de SSL avec CN. Les futures études sur l'efficacité des programmes de réadaptation intégrant des exercices et de l'éducation devraient se concentrer sur des approches plus individualisées pour le patient et explorer des durées variées. L'approche individualisée pour le patient permettrait de mieux cibler les besoins physiques et psychologiques du patient et pourrait contribuer à l'identification de programmes dédiés à des sous-groupes de patients. L'approche individualisée pourrait être comparée à un programme progressif tel que proposé dans l'essai clinique de cette thèse ce qui permettrait de déterminer si le type d'exercices proposé joue un rôle spécifique dans l'amélioration de la capacité de marche des patients ou si c'est le simple fait d'activer physiquement le patient qui permet l'amélioration de la capacité de marche. Ensuite, en examinant des programmes de différentes durées, il serait possible de déterminer la durée optimale nécessaire pour optimiser les résultats. Une étude sur le rapport coût-bénéfice de l'implantation d'un tel programme serait ensuite nécessaire avant de pouvoir le déployer à plus grande échelle.

Les études futures devraient également évaluer l'efficacité des interventions conservatrices en s'intéressant aux phénotypes de la SSL proposés par Comer et ses collègues (Comer et al., 2022). La combinaison de SSL étant courante, l'usage des phénotypes reflète davantage la réalité des patients. Ainsi, en utilisant les phénotypes comme critère d'inclusion, nous obtiendrons un meilleur portrait global de l'efficacité des programmes de réadaptation qui vise l'amélioration des mesures de résultats comme la capacité de marche, l'incapacité et la douleur. Il serait alors possible de confirmer ou de peaufiner l'algorithme sur la trajectoire de soins des patients en tenant davantage en considération la symptomatologie des patients.

Au regard de l'hétérogénéité des outils de mesure utilisés dans les études sur la SSL, il semble également essentiel qu'un comité d'expert se penche sur la création d'un COS. L'usage d'un COS pour la recherche permettrait davantage le regroupement d'études lors de la réalisation de revues systématiques et de méta-analyses. Si les prochains essais cliniques utilisent les mêmes outils de mesure pour les mêmes mesures de résultats cliniques, il sera plus facile d'établir les relations existantes entre ces différentes mesures. Des conclusions et des recommandations plus claires pourraient alors émerger et contribuer à la mise à jour des guides de bonnes pratiques.

Finalement, il serait intéressant d'investiguer l'impact de la chirurgie sur les paramètres de la marche. Une étude de cohorte pourrait être mise en place où les paramètres de la marche de même que les facteurs physiques et psychologiques pourraient être mesurés avant et après la chirurgie de même qu'au rendez-vous postopératoire. Les résultats obtenus pourraient informer les cliniciens sur les besoins en matière de capacité de marche des patients candidats à la chirurgie et pourraient informer sur les modalités du plan de réadaptation physique pour favoriser le retour à un patron de marche normal après la chirurgie.

Conclusion

Les associations contradictoires identifiées entre, d'une part, les facteurs physiques et psychologiques et, d'autre part, la capacité de marche ont mis en lumière l'éventail d'outils de mesure utilisés dans la littérature pour évaluer un même résultat clinique. Cette observation souligne le besoin de mieux définir les mesures de résultats cliniques nécessaires pour l'évaluation globale de la SSL, notamment en ce qui concerne l'incapacité, et d'identifier les outils de mesure les plus pertinents pour cette population, comme le SSSQ. Les travaux de cette thèse ont également mis en évidence que les changements dans les paramètres de marche apparaissent généralement à partir de 70 ans et que les patients ayant un diagnostic de SSL présentent des paramètres de la marche qui diffèrent significativement des personnes âgées de

50 ans et plus, soulignant ainsi l'importance de mesurer les paramètres de la marche pour la pratique clinique. Les différents travaux de cette thèse mettent également en lumière l'utilisation de technologies portables, telles que les capteurs inertiels, pour l'évaluation et le suivi de la marche chez les patients ayant un diagnostic de SSL avec CN. Enfin, les résultats de cette thèse contribuent non seulement à améliorer les connaissances sur cette condition, mais renforcent aussi l'importance et la nécessité d'offrir des options thérapeutiques conservatrices adaptées aux besoins physiques et psychologiques des patients comme les exercices et l'éducation qui dans l'objectif d'améliorer la capacité de marche.

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Annexe A – Article 1, Détails de la recherche bibliographique (Supplement Material 1)

Supplement 1: Example of search strategy

Database: **MEDLINE**

	Non-MeSH	MeSH
Population	Lumbar spinal stenosis	Spinal stenosis
	Neurogenic claudication	Intermittent claudication
Intervention	Walking pattern	Walking
	Gait pattern	Gait analysis
	Walking velocity	Walking speed
	Walking speed	Walking speed
	Gait velocity	Gait velocity
	Gait speed	Gait velocity
	Walking time	Walking
	Gait duration	Gait analysis
	Stride length	N/A
	Step length	N/A
	Spatiotemporal parameters	Spatio-temporal analysis
	Step width	N/A
	Walking asymmetry	Mobility limitation
	Walking symmetry	Walking
	Gait asymmetry	Gait analysis
	Gait cycle	Gait analysis
	Gait cycle duration	Gait analysis
	Gait balance	Postural balance
	Gait disorders	Gait disorders
	Gait stability	Gait
	Stair climbing	Stair climbing
	Climbing	Stair climbing
	Step	Exercise test
	Step ascent	Exercise test
	Step descent	Exercise test
	Running pattern	Running
	Stance phase	N/A
	Swing phase	N/A
	Cadence	N/A
Outcomes	Walking capacity	Walking

	Walking time	Time
	Walking distance	Walking
	Symptoms	Signs and Symptoms
	Pain	Pain
	Functional capacity	N/A
	Walking function	Walking
	Lower limb pain	Pain
	Kinesiophobia	N/A
	Anxiety	Anxiety
	Depression	Depression
	Frailty	Frailty
	Self-efficacy	Self-efficacy

Non-MeSH results

	Key words	Results
S1	**''lumbar spinal stenosis'' OR ''neurogenic claudication''**	5,743
S2	**walk* pattern* OR Gait pattern* OR run* pattern* OR walk* velocity OR walk* speed OR gait velocity OR gait speed OR run* velocity OR run* speed**	25,620
S3	**walk* time OR gait duration OR gait cycle duration OR gait cycle OR stance phase OR swing phase OR cadence**	16,404
S4	**stride length OR step length OR step width OR ''spatiotemporal parameters''**	7,818
S5	**''walk* asymmetr*'' OR ''walk* symmetr*'' OR ''gait asymmetr*'' OR ''gait symmetr*'' OR gait balance OR gait disorder* OR gait stability**	12,896
S6	**Stair* climb* OR Climb* OR step* OR step ascent OR step descent**	711,761
S7	**''walking capacity'' OR ''walking time'' OR ''walking distance'' OR symptoms OR pain OR functional capacit* OR ''walking function'' OR lower limb pain**	1,556,756
S8	**self-efficacy OR frailty OR depression OR anxiety OR kinesiophobia**	570,333
S9	**S2 OR S3 OR S4 OR S5 OR S6**	750,159
S10	**S7 OR S8**	1,965,506
S11	**S1 AND S9 AND S10**	150

MeSH results

	Key words	Results
S1	**''spinal stenosis'' OR ''intermittent claudication''**	17,834
S2	**walk* OR run* OR walk * speed OR gait velocity OR Gait OR Gait disorder* OR gait analysis OR spatio-temporal analysis OR mobility limitation OR postural balance OR Stair climb* OR Exercise* test***	513,674
S3	**walk* OR time OR signs symptoms OR pain**	5,060,536
S4	**anxiety OR depression OR frailty OR self-efficacy**	569,901
S5	**S3 OR S4**	5,477,578
S6	**S1 AND S2 AND S5**	2,738

Annexe B – Article 1, Data extraction (Supplement Material 2)

#	First author, year	Title	Country	Study Design	(N =)	Definitions	Population	Independant variables	Dependant variables	Results	Comments
1	**Conrad et al. 2013**	Associations of self-report measures with gait, range of motion and proprioception in patients with lumbar spinal stenosis	USA	Cross-sectional	25	**LSS:** Spinal stenosis is defined as neurogenic claudication due to narrowing of the spinal canal lumen diameter. Inclusion criteria for LSS = NA **NC:** NA	Patients with symptomatic LSS (N=25) M: F ratio = 11: 14 Age = 62 ± 14 yo	Walking velocity, stride length, cadence, base of support	ODI, SF-12, NRS	***ODI:*** Strongly correlated with step length (r^2=0.58; p<0.001) and gait velocity (r^2=0.506; p=0.001). Weakly correlated with the base of support (r^2=0.363; p=0.008) and left lateral bending proprioception (r^2=0.213; p=0.036). There was no significant correlation between ODI and cadence (r^2=0.182), ROM (r^2= [0.024; 0.163]) and proprioception (extension, flexion and right lateral bending) (r^2= [-0.053; -0.039]). ***SF-12:*** There was no significant correlation between SF-12 and biomechanical measurements (r^2 = [0.001 - 0.183]). ***NRS:*** Weakly correlated with velocity (r^2=0.189; p=0.049) and base of support (r^2=0.219; p=0.032). There was no significant correlation between NRS and step length, cadence, ROM and proprioception (r^2= [0.000 - 0.177])	
2	**Conway et al. 2011**	Walking assessment in people with lumbar spinal stenosis: capacity, performance, and self-report measures	USA and Canada	Prospective laboratory and clinical observational study	12	**LSS:** Characterized by a narrowing of the lumbar spinal canal or nerve root foramen. Symptoms, including back pain, neurological deficits, and pain in the lower limbs.	Patients with LSS with NC (N=12) M: F ratio = 9: 3 Age= 66.3 ±9.8 yo	SPWT distance, SPWT distance to first symptoms, activity count/d, maximum time of continuous activity, QBPDS, ODI, SSSQ, SF-36, Walking, walking capacity,	**Walking capacity** (SPWT distance and SPWT distance to first symptoms) **Walking performance** (Activity count/d and maximum	***Walking capacity:*** Strong correlation between SPWT distance and maximum time of continuous activity per day (r=0.63; p<0.05), QBPDS (total: r=-0.638; p<0.05, walk: r=-0.755; p<0.01, reach: r=-0.650; p<0.05, run: r=-0.664; p<0.05, groceries: r=-0.727; p<0.05), SSSQ (PF: r=-0.610; p<0.05, PF walk: r=-0.715; p<0.05, SS weak: r=-0.742; p<0.01, SS balance: r=-0.673; p<0.05), ODI (r=-0.595; p<0.05), SF-36 physical	13 out of 15 measures (87%) were more highly correlated to the SPWT than the activity monitor.

						Diagnosis was based on patient history, physical examination and MRI **NC:** Pain, numbness, weakness, or tingling in the lower extremity brought on by lumbar extension, standing, or walking.		estimated walking, leg pain.	time of continuous activity)	functioning (r=0.825; p<0.01) and estimated walking distance (r=0.886; p<0.01). There was no significant correlation between SPWT distance and SPWT time to first symptoms, activity count/d, leg pain and QBPDS stand (r= [-0.551 – 0.563]). Strong relationship between SPWT distance to first symptoms and estimated walking (r=0.659; p<0.05), QBPDS stand (r=-0.681; p<0.05) and SSSQ (PF walk: r=-0.622; p<0.05, balance: r=-0.646; p<0.05) There was no significant correlation between SPWT distance to first symptoms and activity count/d, maximum time of continuous, total QBPDS score, ODI, SSSQ PF, SF-36 PF, walking capacity, leg pain, QBPDS (walk, reach, run and groceries) and SSSQ (SS weak) (r= [-0.628 – 0.422]). ***Walking performance:*** Strong relationship between Activity count/d and maximum time of continuous activity (r=0.879; p<0.01), leg pain (r=0.623; p<0.05) and QBPDS run (r=-0.884; p<0.01). There was no significant correlation between Activity count/d and QBPDS (total score, stand, walk, reach and groceries), ODI, SSSQ (PF, PF walk, SS weak and SS balance), SF-36, walking capacity and estimated walking (r= [-0.291 – 0.521]). Strong relationship between maximum time of continuous activity and SPWT distance (r=0.629; p<0.05), activity count/d (r=0.876; p<0.01), leg pain (r=0.754; p<0.01) and QBPDS run (r=-0.825; p<0.01) There was no significant correlation between maximum time of continuous activity and QBPDS (total, stand, walk, reach and groceries), ODI, SSSQ (PF, PF walk, SS weak and SS balance), SF-36, walking capacity and estimated walking (r= [-0.375 – 0.541]).	
3	**Drury et al. 2009**	Degenerative Spondylolisthes is in Patients With	USA	Prospectiv e study	77	**LSS:** NA	Patients with NC secondary to LSS (N=77)	SSSQ, SF-36	**Walking distance** (Shuttle Walking Test)	Strong correlation between walking distance and SSSQ PF (r= -0.52; p<0.001) and SF-36 physical functioning (r= 0.60; p<0.001).	Mean age for all patients was not available.

		Neurogenic Claudication Effects Functional Performance and Self-Reported Quality of Life				Diagnosis was based on clinical symptoms. **NC:** Characterized by pain radiating down the lower extremities in a radicular distribution when a patient is standing of walking and generally relieved by sitting down or leaning forward. Secondary to LSS.	M: F ratio = 39: 38 LSS without spondylolisthesis (N=32) Age = 67.1 ± 9.8 yo LSS with fixed spondylolisthesis (n=22) Age = 70.4 ± 10.9 yo LSS with mobile spondylolisthesis (n=23) Age = 68.6 ± 10.8 yo			Moderate correlation between walking distance and SSSQ (total score: r=-0.50; p<0.001, pain: r= -0.27; p=0.019,sensory: r=-0.36; p=0.002, neuroischemic: r= -0.30; p=0.009), SF-36 (role physical: r= 0.35; p=0.003, bodily pain: r=0.39; p=0.001, general health index: r=0.26; p=0.033 and social functioning: r=0.31; p=0.009). Weak correlation between walking distance and SF-36 vitality (r= 0.24; p=0.041). There was no significant correlation between walking distance and SF-36 role emotional and mental health index subscales (r= [0.06 - 0.075]).	Mean age was available only for subgroup of patients with LSS. However, correlations were done combining all patients from the 3 subgroups.
4	**Fujita et al. 2019**	Stride length of elderly patients with lumbar spinal stenosis: Multi-center study using the Two-Step test	Japan	Cross-sectional study	357	**LSS:** Lumbar spinal canal stenosis (LSS) is a degenerative musculoskeletal disorder characterized by narrowing of the lumbar spinal canal. Diagnosis was based on clinical symptoms and MRI. **NC:** NA	Patients who planned to undergo primary surgery for LSS with leg pain/NC (n=357) M:F ratio= 201: 156 Age= 73.3 ±5.47 yo	Two-Step test Age, sex, JOABPEQ, ZCQ, motor deficit, sagittal vertical axis, and lumbar lordosis	TUGT Stride	Strong correlation between the Two-Step test and the TUGT (r=-0.65; p<0.001). Univariable analysis showed a significant association between short stride with age ≥ 80 years (OR=2.8), score of lumbar function in JOABPEQ <60 (OR=2.9), score of walking ability in JOABPEQ <30 (OR=1.6), score of social life in JOABPEQ <45 (OR=1.6), score of psychological disorder in JOABPEQ <45 (OR=1.9), symptom severity in ZCQ ≥4 (OR=1.8), physical function in ZCQ ≥2.5 (OR=2.0), motor deficit (OR=3.1), and sagittal vertical axis of ≥50 mm (OR=2.4) When adjusting all variables, associations with age ≥ 80 years (OR= 2.3), the score of lumbar function in JOABPEQ of <60 (OR=2.7), motor deficit (OR=2.7) and sagittal vertical axis of ≥50 mm (OR=2.1).	
5	**Gaberlotti et al. 2014**	An investigation of the value of tridimensional kinematic analysis in functional diagnosis of	Brazil	Cross-sectional study, uncontrolled intervention	14	**LSS:** Spine canal space restricted, there may be symptoms, such as pain, numbness, weakness, and	Patients with LSS (N=14) M:F ratio= 10: 4 Age= 74.5 ±9.8 yo	GDI, Kinematics parameters (speed, cadence, stride length, single stance, double stance,	Pain perception (VAS), cross-sectional area of the spinal canal	There was no significant correlation between pain perception pre-effort and kinematic parameters (r= [-0.45; 0.46]). Strong correlation between post-effort pain perception and GDI (left side: r=-0.64; p<0.05 and right side: r=-0.53; p<0.05) but there was	

		lumbar spinal stenosis				neurogenic claudication, which can worsen with effort and improve with rest. Diagnosis was based on medical assessment and MRI. **NC:** Neurogenic claudication is related to compression of the nerve roots in the spinal canal.		swing and trunk tilt)		no other significant correlation with kinematic parameters (r= [-0.42 - 0.19]). There was no significant correlation between cross-sectional area and GDI and kinematic parameters for both pre- and post-effort (r= [-0.34 - 0.34]).	
6	**Grelat et al. 2019**	Walking Speed as an Alternative Measure of Functional Status in Patients with Lumbar Spinal Stenosis	France	Cross-sectional	38	**LSS:** NA Diagnosis was confirmed with MRI. **NC:** NA	Patients with LSS referred to the neurosurgery department and with the ability to walk 10m or more without help (N=38) M: F ratio= 23: 15 Age= 69.3 ±7.9 yo	ODI, QBPDS, SF-12, estimated walking perimeter	Measured walking perimeter, free walking speed, estimated error	Weak correlation between measured walking perimeter and ODI (r= -0.44; p= 0.005). ***Patients estimating their walking perimeter as lower than 500m (n=21):*** Strong correlation between estimated walking perimeter and estimated error (r=-0.63; p=0.002) ***In patients walking less than 500m (n=7):*** Strong correlation between the measured free walking speed and ODI (r= -0.71; p=0.001) and QBPDS (r= -0.5; p= 0.0008) There was no association between SF-12 and estimated walking perimeter, measured walking perimeter and error estimation.	
7	**Igawa et al. 2018**	Kinetic and kinematic variables affecting trunk flexion during level walking in patients with lumbar spinal stenos	Japan	Cross-sectional	111	**LSS:** Caused by narrowing of the spinal canal or the various tunnels through which nerves and other structures communicate with that canal. Diagnosis was based on clinical symptoms and MRI.	Patients with acquired degenerative LSS with leg pain (N=111) M: F ratio= 65: 51 Age= 70.9 ±6.2 yo	Back pain, JOABPEQ, VAS, Step length, velocity, one gait cycle time, maximum pelvis anterior tilt angle, maximum hip flexion and extension angle and moment, maximum knee flexion and extension angle and moment,	Anterior trunk flexion angle	Moderate correlation between anterior trunk flexion angle and maximum pelvis anterior tilt (r=0.29; p<0.01), maximum hip flexion angle (r=0.27; p<0.01), maximum hip extension angle (r=0.47; p<0.01), maximum knee flexion angle (r=0.33; p<0.01), maximum knee extension angle (r=0.33; p<0.01), maximum hip flexion moment (r=0.44; p<0.01) and minimum hip power (r=-0.38; p<0.01). Weak correlation between anterior trunk flexion angle and step length (r=0.17; p=0.01), maximum ankle plantar flexion moment (r=0.20; p<0.01) and maximum knee power (r=0.21; p<0.01)	

						NC: Pain in legs with walking, which is caused by blockage of blood outflow from around the nerves.		maximum ankle dorsi and plantar flexion angle and moment, maximum and minimum hip, knee and ankle power		There was no significant correlation between max trunk flexion angle and VAS, JOABPEQ, velocity, gait cycle time, maximum pelvis rotation angle, maximum ankle dorsi flexion angle, maximum ankle plantar flexion angle, maximum hip extension moment, maximum knee flexion moment, maximum knee extension moment, maximum ankle dorsi flexion moment, maximum hip power, minimum knee power, maximum ankle power and minimum ankle power (r=[-0.11 - 0.12]). Maximum hip extension angle (β=0.42), maximum hip flexion moment (β=-0.35) and step length (β=0.26) were able to explain 29% of the variance.	
8	**Inoue et al. 2020**	Handgrip strength correlated with walking in lumbar spinal stenosis	Japan	Retrospective	183	**LSS:** Symptoms of LSS involve lower back pain, lower extremity pain, lower extremity numbness, lower muscle weakness and gait disturbance. Inclusion criteria for patients with LSS: confirmed diagnosis through neurologic examination and imaging. **NC:** NA	Patients with LSS NC or radicular leg pain M:F ratio = 128: 55 Age = 70.5 yo (range 36-88 yo)	10-meter walk test (time and step), 300m walking distance test, psoas muscle index, leg extension power, intermittent claudication	Handgrip strength	Strong correlation between handgrip strength and leg power extension (r=0.723 ; p<0.001) Weak significant negative correlation between handgrip strength and 10-meter walk test time (r=-0.269 ; p<0.001), and 10-meter walk test steps (r=-0.352 ; p<0.001). There was a significant weakly positive correlation between handgrip strength and intermittent claudication (measure with the 300 m walking distance test) (r=0.201 ; p=0.008).	
9	**Ishimoto et al. 2012**	Prevalence of symptomatic lumbar spinal stenosis and its association with physical performance in a population-based cohort in Japan: the Wakayama Spine Study	Japan	Cross-sectional study	1009	**LSS:** Symptomatic lumbar spinal stenosis (LSS) is usually associated with impaired walking and other disabilities in the elderly. Inclusion criteria for patients with LSS: NA **NC:** NA	Total study M: F ratio = 335: 674 Age = 66.3 ±13.6 yo *Group 1:* symptomatic LSS (N= 94) *Group 2:* non-symptomatic LSS (N=915)	Symptomatic LSS	6-m walking time at a usual pace, 6-m walking time at a maximal pace, Chair standing time, One leg standing time	6-m walking time at a maximal pace was significantly associated with symptomatic LSS (OR = 1.17). There was no significant association between 6-m walking time at a usual pace (OR=1.04), chair standing time (OR= 1.03) and one-leg standing time (OR =1.00) in symptomatic LSS.	The article did not mention the mean age for the LSS group. The article did not mention sex ratio for the LSS group.

10	**Kim et al. 2011**	The Risk Assessment of a Fall in Patients With Lumbar Spinal Stenosis	Korea	Prospective case-control study (observational study)	80	**LSS:** Degenerative arthritic disease in the spine that results in decreasing function, impaired balance, and gait deficit, with increased levels of leg and back pain. Diagnosis was based on walking intolerance and MRI. **NC:** Walking impairment is the main symptom of LSS and is caused by neurogenic claudication, which leads to limited ambulation, decreased daily activity, and muscle weakness.	Patients with LSS with NC (N=40) M: F ratio= 11: 29 Age= 62.82 ±7.29 yo	ODI	Alternative-Step test, Six-Meter-Walk test, Sit-to-Stand test, TUGT	There was no significant correlation between the ODI score and the four functional mobility tests.	
11	**Kuittinen et al. 2014**	Correlation of lateral stenosis in MRI with symptoms, walking capacity and EMG findings in patients with surgically confirmed lateral lumbar spinal canal stenosis	Finland	Prospective study	14	**LSS:** Buttock or lower extremity pain, which may occur with or without back pain, associated with diminished space available for the neural and vascular elements in the lumbar spine. Diagnosis was based on clinical and imaging findings. **NC:** NA	Patients with LSS with leg pain and/or NC (N=14) M:F ratio= 6: 8 Age= 58 (range 48-76) years old	MRI findings	BDI, VAS, ODI, EMG, walking distance	MRI findings (severity of entrance stenosis, mid zone entrance zone width, mid zone area) did not correlate with ODI, VAS, specific low back pain, specific leg pain, BDI and walking distance. Abnormal EMG is significantly correlated to MRI findings (severity of mid zone stenosis) in supine position (p=0.015).	No correlation results are available in this study. Authors just mentioned if there were correlations or not.
12	**Kuwahara et al. 2019**	Correlation between spinal and pelvic movements during gait and aggravation of low back pain by gait loading in lumbar spinal stenosis	Japan	Cross-sectional	29	**LSS:** Lumbar spinal stenosis patients frequently complain of numbness and pain in the lower limbs, and neurogenic intermittent claudication.	Patients with LSS with leg pain and/or NC (N= 29) M: F ratio= 17: 12 *Group1* (n=8): leg pain and LBP changes	Velocity, peak trunk tilt, peak thoracic tilt, peak lumbar tilt, peak pelvic tilt	Changes in leg pain Changes in low back pain	***Changes in leg pain*** Moderate correlation between leg pain changes and peak trunk tilt pre-effort (r=-0.455; p=0.044). There was no significant correlation between leg pain changes and velocity, peak trunk tilt post effort, trunk changes, peak thoracic tilt, peak lumbar tilt and peak pelvic tilt (r= [-0.206 - 0.286]).	Non-change group was excluded of the correlation.

						Diagnosis was base on patient history, physical examination and MRI. **NC:** NA	Age= 72 ± 7 yo *Group2* (n=12): leg pain changes only Age= 69 ± 8 yo *Group3* (n=9): non-change Age= 71 ± 9 yo			***Changes in low back pain*** Moderate correlation between low back pain changes and peak lumbar tilt pre (r=-0.508; p=0.022) and post (r=-0.503; p=0.024) effort and changes in pelvis variation (r=0.506; p=0.023). There was no significant correlation between low back pain change and velocity, peak trunk tilt, peak thoracic tilt, changes in lumbar spine and peak pelvic tilt pre- and post-effort (r= [-0.274 - 0.343]).	
13	**Minetama et al. 2020**	Associations between psychological factors and daily step count in patients with lumbar spinal stenosis	Japan	Secondary analysis of a RCT	71	**LSS:** LSS characterized by NC. Diagnosis was based on clinical examination and MRI findings **NC:** defined as leg pain, numbness, and heaviness brought on by walking but relieved by sitting.	Patients with LSS with NC (N=71) M: F ratio = 35: 36 Age ± SD = 71.6 ± 5.6	Age, sexe, BMI, number of stenoses, duration of symptoms, severity of stenosis, walking distance on the SPWT, ZCQ, NRS (leg and LBP), PCS, PASS-20 (total score, cognitive anxiety, escape/avoidance, fear), TSK-11 and HADS depression score	Daily step count	Strong correlation between daily step count and age (r = – 0.543 ; p<0.05), number of stenoses (r = 0.260 ; p<0.05), severity of stenosis at L3–L4 (r = 0.279 ; p<0.05), walking distance on the SPWT (r = 0.338 ; p<0.05), PASS-20 total score (r = – 0.327 ; p<0.05); cognitive anxiety (r = – 0.352 ; p<0.05); escape/avoidance (r = – 0.235 ; p<0.05); fear (r = – 0.284 ; p<0.05), and HADS depression score (r = – 0.245 ; p<0.05) There was no significant correlation between daily step count and sexe, BMI, duration of symptoms, severity of stenosis (L1-L2, L2-L3,L4-L5,L4-S1), ZCQ, NRS (leg and LBP), PCS, and TSK-11 (p>0.05).	
14	**Nagai et al. 2014**	Quantification of Changes in Gait Characteristics Associated With Intermittent Claudication in Patients With Lumbar Spinal Stenosis	Japan	Cross-sectional observational study	11	**LSS:** NA Diagnosis was based on patient history, physical examination and MRI. **NC:** Pain, numbness, weakness, or tingling in the lower extremities brought on by lumbar extension, standing, or walking	Patients with LSS with NC (N=11) M: F ratio= 8: 3 Age= 72.8 ± 5.5 yo	RMS, autocorrelation coefficient, stride frequency, coefficient of variance	Maximum walking distance	Strong correlation between maximum walking distance and RMS at the cervical sensor (r=-0.64; p=0.03) and coefficient of variance (r=-0.66; p=0.03). There was no significant correlation between maximum walking distance and RMS at the lumbar sensor, autocorrelation coefficient for both cervical and lumbar sensor position and stride frequency (r= [-0.55 - 0.53]).	

15	**Özdermir et al 2015**	Quality of life and related factors in degenerative lumbar spinal stenosis: A controlled study	Turkey	Cross-sectional study (controlled)	108	**LSS:** Lumbar spinal stenosis (LSS) is a common degenerative disease that occurs narrowing of the spinal canal, neural foramen and lateral recess due to changes in the soft tissue or bone. Diagnosis was based on clinical findings and MRI. **NC:** NA	*Group 1* (n=54): Patients with diagnosis of LSS by clinical findings and MRI M: F ratio = 9: 45 Age= 68.06 ± 9.55 yo *Group 2* (n=54): Healthy age and sex matched M: F ratio =11: 43 Age = 67.15 ± 9.50 yo	ODI, HADS, Walking distance, Comorbidities, Duration of symptoms, Number of spinal segments with stenosis	**SF-36** (physical health, mental health and total)	***Physical health*** Strong correlation between physical health and ODI (r= −0.713; p<0.001) and HADS-A (r= −0.583; p<0.001). Moderate correlation between physical health and HADS-D (r= −0.479; p<0.001) and walking distance (r= 0.476; p<0.001). ***Mental health*** Strong correlation between mental health and ODI (r= −0.638; p<0.001), HADS-A (r= −0.682; p<0.001) and HADS-D (r= −0.569; p<0.001). Moderate correlation between mental health and walking distance (r= 0.319; p<0.05). ***Total SF-36*** Strong correlation between total SF-36 score and ODI (r= −0.715; p<0.001), HADS-A (r= −0.627; p<0.001) and HADS-D (r= −0.522; p<0.001). Moderate correlation between total SF-36 and walking distance (r= 0.458; p<0.05). No correlation was found between the SF-36 scores and comorbidities, duration of symptoms and the number of spinal segments with stenosis.	*Age and sex matched pas respecté* *Walking distance was not explained in the study.*
16	**Pryce et al. 2012**	Relationship Between Ambulatory Performance and Self-Rated Disability in Patients With Lumbar Spinal Stenosis	Canada	Cross-sectional study	33	**LSS:** NA Diagnosis was based on symptoms and MRI. **NC:** Activity-generated, neutrally mediated lower limb pain, paresthesia, or cramping.	Patients with LSS with NC (N=33) M: F ratio = NA Age= 68.5 ± 8.4 yo	SF-36, RMDQ, ODI, DASH, VAS (back and leg pain)	**Physical activity** (volume, intensity, duration) **Ambulatory behavior** (bout length, maximum bout length) **Sedentary behavior** (duration, bout length, maximum bout length)	***Physical activity:*** There were significant moderate to strong correlations between PA volume and SF-36, disability and pain (r=[-0.58 – 0.64]. There were significant moderate to strong correlations between PA intensity and SF-36 (total score, physical health, mental health and physical function) and disability (r= [-0.49 – 0.55]). There was no significant correlation between PA intensity and SF-36 (bodily pain) and pain (back pain intensity, leg pain intensity, back pain function and leg pain function).	*p<0.05 when r>0.35* *p<0.01 when r>0.45*

										There were significant moderate to strong correlations between PA duration and SF-36, disability and pain (back pain intensity, back pain function and leg pain function (r= [-0.50 – 0.58]). There was no significant correlation between PA duration and leg pain intensity (r= -0.26). Regression models for physical activity showed that PA volume was predicted by SF-36 physical function and RMDQ (r^2= 0.43; p= 0.001), intensity was predicted by SF-36 physical function (r^2= 0.28; p= 0.001) and duration was predicted by SF-36 physical function (r^2= 0.31; p= 0.01) ***Ambulatory behavior (meaningful intensity)*** There were significant moderate to strong correlations between bout length and maximum bout length and SF-36, disability and back pain (r= [-0.51 – 0.73]. There were significant moderate correlations between maximum bout length and pain (back pain function (r= -0.39) and leg pain function (r= -0.43)). Regression models for meaningful activity showed that bout length was predicted by SF-36 physical function (r^2= 0.28; p=0.001) and that maximum bout length was also predicted by SF-36 physical function (r^2 = 0.52; p< 0.001). ***Ambulatory behavior (moderate intensity)*** There were significant moderate to strong correlation between bout length and SF-36 (total score, physical health, physical function and bodily pain), disability (RMDQ and ODI) and pain (leg pain intensity). There was no significant correlation between bout length and SF-36 (mental health), disability (DASH) and pain (back pain intensity, back pain function and leg pain function) (r= [-0.30 – 0.32]). There were significant moderate to strong correlation between maximum bout length and SF-36 (total score, physical health, mental health and physical function), disability	

										(RMDQ, ODI and DASH) and leg pain intensity (r= [-0.55 – 0.61]. There was no significant correlation between maximum bout length and SF-36 (bodily pain) and pain (back pain intensity, back pain function and leg pain function) (r= [-0.34 – 0.33]). Regression models for moderate activity showed that bout length was predicted by SF-36 physical function, leg pain intensity and back pain intensity (r^2= 0.38; p< 0.01) and tht maximum bout length was predicted by SF-36 physical function and ODI (r^2= 0.38; p< 0.001). ***Sedentary behavior*** There was no correlation between dependant variables (duration, bout length and maximum bout length) and independent variables (SF-36, disability and pain) (r= [-0.34 – 0.32]). Regression models for sedentary behavior showed that bout length was predicted by SF-36 physical function and back pain intensity (r^2= 0.22; p= 0.01). There were no predictors for duration and maximum bout length.	
17	**Quack et al. 2019**	Psychological factors outmatched morphological markers in predicting limitations in activities of daily living and participation in patients with lumbar stenosis	Germany	Cross-sectional	67	**LSS:** Degenerative lumbar spinal stenosis is related to narrowing of the lumbar spinal canal and is associated with degenerative changes of the joint complex, osteophyte formation and ligamentum flavum thickening. Diagnosis was based on clinical evaluation and MRI. **NC:** NA	Patients with degenerative LSS (n=67) M: F ratio = 34: 33 Age = 62.5 ± 11.7 yo	Age, gender, duration of disease, the three morphological markers (Schizas classification, number of stenotic segments and presence of a spondylolisthesis), depression and fear of movement	Pain interference (PI-G), performance of ADLs (RehaCAT subscales), participation (AAPI-Part)	***PI-G:*** PI-G mental was strongly correlated with DESC (r= 0.55; p<0.01). PI-G mental was weakly correlated with number of stenotic segments (r= -0.28; p<0.05), TSK (SF: r= 0.28; p<0.05 and AA: r= 0.25; p<0.05). There was no significant correlation between PI-G mental and age, gender, disease duration, spondylolisthesis and Schizas classification (r= [-0.16 – 0.22]). PI-G functional was moderately correlated with DESC (r= 0.48; p<0.01) and TSK (AA: r= 0.30; p<0.05). PI-G functional was weakly correlation with gender (r= 0.29; p<0.05 and number of stenotic segments (r=-0.25; p<0.05). There was no significant correlation between PI-G functional and age, disease duration, spondylolisthesis, Schizas classification and TSK SF (r= [-0.19 - -0.01]).	

										PI-G physical was moderately correlated with DESC (r= 0.35; p<0.05) and was weakly correlated with TSK (SF: r= 0.26; p<0.05). There was no significant correlation between PI-G physical and gender, age, disease duration, spondylolisthesis, number of stenotic segments, Schizas classification and TSK AA (r= [-0.11 – 0.24]). ***RehaCAT:*** RehaCAT lower extremity was strongly correlated with TSK SF (r=0.52; p<0.01) and moderately correlated with Schizas classification (r= 0.32; p<0.05), DESC (r= 0.43; p<0.01) and TSK AA (r= 0.45; p<0.01). There was no significant correlation between RehaCAT lower extremity and gender, age, disease duration, spondylolisthesis and number of stenotic segments (r =[-0.17 – 0.20]). RehaCAT upper extremity was strongly correlated with TSK SF (r=0.64; p<0.01) and moderately correlated with DESC (r= 0.40; p<0.01) and TSK AA (r=0.45; p<0.01). There was no significant correlation between RehaCAT and age, gender, disease duration and morphological markers (r= [-0.03 – 0.23]). RehaCAT activities of daily living was moderately correlated with DESC (r= 0.45; p<0.01) and TSK (SF: r= 0.43; p<0.01 and AA: r= 0.44; p<0.01). RehaCAT activities of daily living was weakly correlated with gender (r= 0.29; p<0.05) and disease duration (r= -0.27; p<0.05). There was no significant correlation between RehaCAT activities of daily living and age, spondylolisthesis, number of stenotic segment and Schizas classification (r= [-0.18 – 0.10]. ***AAPI participation:*** AAPI participation subscale was strongly correlated with DESC (r= -0.57; p<0.01), moderately correlated with TSK SF (r= -0.39; p<0.01) and weakly correlated with number of stenotic segments (r= 0.26; p<0.05).	

										There was no significant correlation between AAPI participation and gender, age, disease duration, spondylolisthesis, Schizas classification and TSK AA (r= [-0.25 – 0.20]). DESC alone predict PI-G mental (r^2=0.32) and PI-G physical (r^2= 0.12). DESC combined with TSK AA predict PI-G functional (r^2=0.28) and RehaCAT activities of daily living (r^2= 0.38). DESC combined with TSK SF predict AAPI participation (r^2= 0.40). DESC combined with TSK SF and Schizas classification predict RehaCAT lower extremity (r^2= 0.39) TSK SF alone predict RehaCAT upper extremity (r^2=0.40).	
18	**Schmidt et al. 2017a**	Association of Neuromuscular Attributes With Performance-Based Mobility Among Community-Dwelling Older Adults With Symptomatic Lumbar Spinal Stenosis	USA	Cross-sectional study	300	**LSS:** NA Diagnosis was bas on the combination of imaging-detected LSS and self-reported NC. **NC:** Pain, numbness or weakness in the lower extremities that worsens with spinal extension and improves with spinal flexion.	Patients with LSS *Group1* (n=54): Patients with symptomatic LSS Age = 76.9 ± 6.6 yo *Group2* (n=246): Patients with no symptomatic LSS Age = 77.1 ± 7.2 yo	Trunk extensor muscle endurance, leg strength, leg strength asymmetry, leg speed, maximum knee flexion ROM and asymmetry, maximum knee extension ROM and asymmetry, ankle ROM and kyphosis	**Performance-based measures of mobility** (SPPB total score, HGS and Chair Stand)	***SPPB total score:*** Trunk extensor muscle endurance, leg strength asymmetry and leg speed were weakly associated with the SPPB score (r^2= 0.24). ***HGS:*** Trunk extensor muscle endurance, knee flexion ROM and knee extension asymmetry were weakly associated with HGS (r^2= 0.35). ***Chair stand test:*** Leg strength was weakly or poorly associated with Chair Stand test (r^2= 0.19).	
19	**Sigmundsson et al. 2011**	Correlation between disability and MRI findings in lumbar spinal stenosis	Sweden	Prospective study	109	**LSS:** dural sac area of 70 mm2, presence of NC, persistent leg and/or back pain and weakness and numbness in one or both legs. **NC:** NA	Patients with a central spinal stenosis planned for a surgery M:F ratio = 53: 56 Age = 71 ± 10 yo	Estimated walking distance, VAS (leg and back), ODI, SF-36 (bodily pain, PF, role physical, general health) and EQ-5D	Minimal dural sac area and multilevel stenosis	***Minimal dural sac area:*** There was no significant correlation between minimal dural sac area estimated walking distance, VAS (leg and back), ODI, SF-36 (bodily pain, PF, role physical, general health) and EQ-5D) (r= [-0.11 – 0.13]). ***Multilevel spinal stenosis:*** There was a weak correlation between VAS (leg) and multilevel spinal stenosis (r=-0.24; p=0.0).	Estimated walking distance was measured in 105 participants. **Controlling for number of levels involved*

										There was no significant correlation between multilevel spinal stenosis and estimated walking distance, VAS (back), ODI, SF-36 (bodily pain, PF, role physical, general health) and EQ-5D) (r= [-0.14 – 0.10]).	
20	**Thornes et al. 2018a**	Degenerative lumbar spinal stenosis and physical functioning: an exploration of associations between self-reported measures and physical performance tests	Norway	Cross-sectional study	103	**LSS:** NA Diagnosis was based on symptoms and radiological findings. **NC:** NA	Patients with a symptomatic and radiological verified central spinal stenosis M:F ratio = 48 : 55 Age= 71.3 ±7.3 yo	OLS in 30 seconds, tandem walking 2 m, functional leg strength (30-s SS), stair climbing (10 steps up and 10 steps down), Duration of present lumbar pain, duration of present leg pain, HSCL25, age, gender and BMI	SYMP and FUNC scales from the SSSQ	***SYMP scale:*** Moderate correlation between SYMP scale and 30-s SS (r= -0.32; p=0.01), stair climb (r= 0.40; p=0.01), OLS (r= -0.33; p=0.01), duration of present lumbar pain (r= 0.25; p=0.05), duration of present leg pain (r=0.31; p=0.01) and HSCL25 (r= 0.39; p=0.01). There was no significant correlation between SYMP scale and tandem walk, age, gender and BMI (r= [-0.20 – 0.16]). ***FUNC scale:*** Strong correlation between FUNC scale and stair climb (r= 0.58; p=0.01). Moderate correlation between FUNC scale and 30/s SS (r= -0.44; p= 0.01), tandem walk (r= -0.29; p= 0.01), OLS (r= -0.28; p= 0.01), gender (r= -0.22; p= 0.05), duration of present lumbar pain (r= 0.26; p= 0.01) and HSCL25 (r= 0.50; p= 0.01). There was no significant correlation between FUNC scale and age, BMI and duration of present leg pain (r= [0.04 – 0.18]).	
21	**Thornes et al. 2018b**	Dynamic balance in patients with degenerative lumbar spinal stenosis; a cross-sectional study	Norway	Cross-sectional study	62	**LSS:** NA Diagnosis was based on symptoms and radiological findings. **NC:** NA	Patients with MRI-verified LSS. M: F ratio = 33: 29 Age = 71.2 ± 7.1 yo	Mini-BESTest **Control systems** (anticipatory adjustment, reactive response, sensory orientation and stability in gait)	FUNC scale and ODI	***FUNC scale:*** Adjusted linear regression showed a significant association between FUNC scale and Mini-BESTest (b= -0.1; p= 0.042). There were no significant association between FUNC scale and four control system. Participants dynamic balance explain 16.7% of the variation in FUNC. ***ODI:*** Adjusted linear regression showed a significant association between ODI and Stability in Gait (b= -5.3; p=0.001)	Participants were sometimes divided in three or two groups (correlation, bivariate correlation).

										There was no significant association between ODI and Mini-BESTest and the others control systems.	
22	**Tomkins-Lane, 2013**	Predictors of objectively measured walking capacity in people with degenerative lumbar spinal stenosis	Canada	Cross-sectional	49	**LSS:** Characterized by a narrow spinal canal and/or narrow nerve root foramina, resulting from degenerative changes in the spine. Diagnosis was based on patient history, physical examination and MRI. **NC:** Progressive onset of pain and neuromuscular deficit including numbness, tingling, and weakness in the low back, buttocks, and legs. These symptoms are initiated by standing or lumbar extension and exacerbated by walking	Patients with LSS with NC or walking limitations (N=49) M: F= 25: 24 Age= 65.8 ±10.0 yo	*Domains:* demographic (age and gender), pain location, duration of pain, pain severity, pain related disability, severity of neurological symptoms (numbness, weakness, tingling), location of neurological symptoms, balance problems and health-related quality of life *Questionnaires used:* ODI, SSSQ, HUI, VAS	**Walking capacity** (SPWT distance)	Variable retained from the domain-specific regression models explaining walking capacity were: years of leg pain, pre-test leg pain severity (VAS), ODI, SSSQ (symptom severity subscale item #7) and HUI. *Duration of pain:* Moderate correlation between walking capacity and years of back pain (r=0.29; p<0.05) and years of leg pain (r=0.42; p<0.01). *Pain severity:* Moderate correlation between walking capacity and SSSQ symptom scale (r=-0.28; p<0.05) and pre-walk leg VAS (r=-0.32; p<0.05). *Pain related function:* Strong correlation between walking capacity and ODI (r=0.52; p<0.01). Moderate correlation between walking capacity and HUI Q8 (r=-0.35; p<0.05) and HUI Q15 (r=-0.33; p<0.05). Severity of neurologic symptoms: Moderate correlation between walking capacity and balance problems (r=-0.40; p<0.01). Health related quality of life: Moderate correlation between walking capacity and HUI score (r=0.38; p<0.05).	
23	**Tong et al. 2007**	Comparing Pain Severity and Functional Status of Older Adults without Spinal Symptoms, with Lumbar Spinal Stenosis, and with Axial Low Back Pain	USA	Cross-sectional	48	**LSS:** NA **NC:** NA	*Group 1* (n=24): Patients with lumbar spinal stenosis M: F 14: 10 Age = 68.6 ± 6.8 yo *Group 2* (n=12): Patients with axial back pain *Group 3* (n=12): asymptomatic	Pain (VAS), 15 min walk test and 7-day walking distance	PDI, QBPDS	Pain VAS was significantly related to QBPDS (β= 0.54; p=0.03) and to PDI (β= 0.76; p=0.002) in spinal stenosis patients. There was no signification association between QBPDS or PDI with 15-min walk test and 7-day walking test.	
24	**Zeifang et al. 2008**	Gait analysis does not correlate with	Germany	Cross-sectional	63	**LSS:** Narrowing of the spinal canal.	Patients with symptomatic LSS (N=63)	Demographic data (age, BMI), functional status,	Walking distance	A significant correlation was observed between the objectively measured walking distance and the BMI (tau b= -0.194; p=0.025),	

		clinical and MR imaging parameters in patients with symptomatic lumbar spinal stenosis				Diagnosis was based on symptoms and MRI. **NC:** Limited walking distance (pain in lower extremities aggravated by walking and lumbar extension and alleviated with lumbar flexion)	M:F ratio = 26: 37 Age= 68 yo (median)	CES-D, cross-sectional area of the overall dural tube, number of segments with a cross-sectional area of less than 70 mm^2		functional status (tau b=0.225; p=0.011) and the cross-sectional area of the dural tube at L1/2 (tau b=-0.118; p=0.032). There was no significant correlation between walking distance and depression status (CES-D).	

Annexe C – Article 1, Quality assessment (Supplement Material 3)

Quality assessment (Appraisal tool for Cross-Sectional Studies (AXIS))

Study/Criteria	1.	2.	3.	4	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.*	15.	16.	17.	18.	19.**	20.	Total score
Conrad et al. (2013)	1	1	0	0	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	15
Conway et al. (2010)	1	1	0	1	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	16
Drury et al. (2009)	1	1	1	1	1	1	0	1	1	1	1	0	0	NA	1	1	1	1	1	1	16
Fujita et al. (2019)	1	1	0	1	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	16
Gaberlotti et al. (2014)	1	1	0	1	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	16
Grelat et al. (2018)	1	1	0	1	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	16
Igawa et al. (2018)	1	1	0	1	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	16
Inoue et al. (2020)	1	1	0	1	1	1	0	1	0	1	0	1	0	NA	1	-	1	1	1	1	13
Ishimoto et al. (2012)	1	1	0	0	1	1	0	1	1	0	0	1	0	NA	1	1	1	1	1	1	13
Kim et al. (2011)	1	1	0	1	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	0	15
Kuittinen et al. (2014)	1	1	0	1	1	0	0	1	1	1	1	0	0	NA	1	0	1	1	1	1	13
Kuwahara et al. (2018)	1	1	0	0	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	15
Minetama et al. (2020)	1	1	0	0	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	15
Nagai et al (2013)	1	1	0	1	0	0	0	1	-	1	0	1	0	NA	1	1	1	1	1	1	12
Özdemir et al. (2015)	1	1	0	0	1	0	0	1	1	1	0	0	0	NA	-	1	1	1	1	1	11
Pryce et al. (2012)	1	1	1	0	1	1	0	1	1	1	1	-	0	NA	1	1	1	1	1	1	15
Quack et al. (2019)	1	1	0	1	1	1	0	1	1	0	1	1	0	NA	0	1	1	1	1	1	14
Schmidt et al. (2017)	1	1	0	1	1	1	0	1	1	1	0	1	0	NA	0	1	1	1	1	0	13
Sigmundsson et al. (2011)	1	1	0	0	1	-	0	1	0	1	0	0	0	N/A	0	1	1	0	1	1	9
Thornes et al. a (2018)	1	1	0	1	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	16
Thornes et al. b (2018)	1	1	0	1	1	1	0	1	1	1	1	1	0	NA	1	1	1	1	1	1	16
Tomkins et al. (2013)	1	1	0	1	1	0	0	1	1	1	1	1	-	NA	1	0	1	1	1	1	14
Tong et al. (2006)	1	1	0	0	-	0	0	0	1	0	0	1	0	NA	1	1	1	1	1	1	10
Zeifang et al. (2008)	1	1	0	1	1	0	0	1	1	1	1	1	0	NA	1	1	1	1	1	0	14
Total (nb of "yeses" per questi	24	24	2	16	22	17	0	23	21	21	17	19	0	N/A	20	21	24	23	24	21	

*Question 14 was removed of the total score because the question is not applicable

**This question was given one point when it was specified that there was no conflict of interest

Legend: 1 = yes ; 0 = no; – = do not know; NA = not applicable

Blue (Quality of reporting) = Questions 1, 4, 10, 11, 12, 16, and 18

Orange (Study design quality) = Questions 2, 3, 5, 8, 17, 19, and 20

Green (Risk of bias) = Questions 6, 7, 9, 13, 14, and 15

Questions/Criteria

Introduction

1. Were the aims/objectives of the study clear?

Methods

2. Was the study design appropriate for the stated aim(s)?
3. Was the sample size justified?
4. Was the target/reference population clearly defined? (Is it clear who the research was about?)
5. Was the sample frame taken from an appropriate population base so that it closely represented the target/reference population under investigation?
6. Was the selection process likely to select subjects/participants that were representative of the target/reference population under investigation?
7. Were measures undertaken to address and categorise non-responders?
8. Were the risk factor and outcome variables measured appropriate to the aims of the study?
9. Were the risk factor and outcome variables measured correctly using instruments/measurements that had been trialled, piloted or published previously?
10. Is it clear what was used to determined statistical significance and/or precision estimates? (e.g. p-values, confidence intervals)
11. Were the methods (including statistical methods) sufficiently described to enable them to be repeated?

Results

12. Were the basic data adequately described?
13. Does the response rate raise concerns about non-response bias?
14. If appropriate, was information about non-responders described?
15. Were the results internally consistent?
16. Were the results presented for all the analyses described in the methods?

Disussion

17. Were the authors' discussions and conclusions justified by the results?
18. Were the limitations of the study discussed?

Other

19. Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?
20. Was ethical approval or consent of participants attained?

Annexe D – Article 1, Extraction des données (Supplement Table 1)

Supplementary table 1. Data extraction regarding associations between physical and psychological factors, and the three outcome categories (walking capacity, functional tasks, and gait pattern characteristics).

First author, year	N	Participants included in associations	Associations with walking capacity	Associations with gait pattern characteristics	Associations with functional tasks
Conrad et al. 2013	25	Patients with symptomatic LSS M: F ratio = 11: 14 Age ± SD= 62 ± 14 yo	Physical factors NA Psychological factors NA	Physical factors ***Pain*** **Velocity – NRS (r^2=0.189; p=0.049)** **Base of support – NRS (r^2=0.219; p=0.032)** Step length, cadence, ROM and proprioception – NRS (r^2= [0.000 - 0.177] ; p>0.05) ***Disability*** **Step length r^2 – ODI =0.58; p<0.001)** **Gait velocity – ODI (r^2=0.506; p=0.001)** **Base of support – ODI (r^2=0.363; p=0.008)** **Left lateral bending proprioception – ODI (r^2=0.213; p=0.036).** Cadence – ODI (r^2=0.182 ; p=0.057) ROM – ODI (r^2= [0.024; 0.163] ; p>0.05) Proprioception (extension, flexion and right lateral bending) – ODI (r^2= [-0.053; -0.039] ; p> 0.05). ***QoL*** SF-12 – biomechanical measurements (velocity, cadence, step length, base of support, proprioception, ROM) (r^2 = [0.001 - 0.183] ; p>0.05). Psychological factors NA	Physical factors NA Psychological factors NA
Conway et al. 2011	12	Patients with LSS with NC M: F ratio = 9: 3 Age ± SD = 66.3 ± 9.8 yo	Physical factors ***Pain*** SPWT distance – leg pain (r=0.492 ; p>0.05) SPWT time to first symptoms – leg pain (r=0.216 ; p>0.05) ***Disability*** **SPWT distance – QBPDS (total: r=-0.638; p<0.05, walk: r=-0.755; p<0.01, reach: r=-0.650; p<0.05, run: r=-0.664; p<0.05, groceries: r=-0.727; p<0.05**, stand (r= -0.551 ; p>0.05) **SPWT time to first symptoms – QBPDS stand (r=-0.681; p<0.05,** total score r=-0.549 ; p>0.05, walk: r=-0.439 ;	Physical factors NA Psychological factors NA	Physical factors ***Pain*** **Activity count per day – leg pain (r=0.623; p<0.05)** **Maximum time of continuous activity per day – leg pain (r=0.754; p<0.01)** ***Disability*** **Activity count per day – QBPDS run (r=-0.884; p<0.01)** Activity count per day – QBPDS (total score, stand, walk, reach and groceries r=[-0.291 to -0.065] ; p>0.05) **Maximum time of continuous activity per day – QBPDS run (r=-0.825; p<0.01)** Maximum time of continuous activity per day – QBPDS (total score, stand, walk, reach and groceries r=[-0.282 - -0.162] ; p>0.05)

			p>0.05, reach: r=-0.436 ; p>0.05, run: r=-0.151 ; p>0.05, groceries: r=-0.628 ; p>0.05) **SPWT distance – SSSQ (PF: r=-0.610; p<0.05, PF walk: r=-0.715; p<0.05, SS weakness: r=-0.742; p<0.01, SS balance: r=-0.673; p<0.05)** **SPWT time to first symptoms – SSSQ (PF walk: r=-0.622; p<0.05, SS balance: r=-0.646; p<0.05,** weakness (r=-0.463 ; p>0.05) **SPWT distance – ODI (r=-0.595; p<0.05)** SPWT time to first symptoms – ODI (r=-0.310 ; p>0.05) ***QoL*** **SPWT distance – SF-36 physical functioning (r=0.825; p<0.01)** SPWT time to first symptoms – SF-36 physical functioning (r=0.325 ; p>0.05) ***Other self-reported outcomes*** Strong relationship between SPWT distance and estimated walking distance (r=0.886; p<0.01). Strong relationship between SPWT time to first symptoms and estimated walking (r=0.659; p<0.05) ***Other objectives measures*** **SPWT distance – maximum time of continuous activity per day (r=0.629; p<0.05)** **Activity count per day – maximum time of continuous activity per day (r=0.879; p<0.01)** Activity count per day – self-reported walking capacity (r=0.304 ; p>0.05) Activity count per day – SPWT distance (r=0.527 ; p>0.05) Activity count per day – SPWT time to first symptoms (r=-0.075 ; p>0.05) Maximum time of continuous activity per day – SPWT time to first symptoms (r=0.344 ; p>0.05) Maximum time of continuous activity per day – self-reported walking capacity (r=0.265 ; p>0.05) <u>**Psychological factors**</u> NA		Activity count per day per day– ODI (r=-0.148 ; p>0.05) Maximum time of continuous activity – ODI (r=-0.070 ; p>0.05) Activity count per day – SSSQ (PF walk, SS weakness and SS balance r=[-0.249 – 0.127] ; p>0.05) Maximum time of continuous activity per day– SSSQ (PF walk, SS weakness and SS balance r=[-0.375 - -0.072] ; p>0.05) ***QoL*** Activity count per day – SF-36 (r= 0.521 ; p>0.05) Maximum time of continuous activity – SF-36 (r= 0.500 ; p>0.05) ***Other objectives measures*** **Activity count per day – maximum time of continuous activity (r= 0.879 ; p<0.01)** <u>**Psychological factors**</u> NA
Drury et al. 2009	77	Patients with NC secondary to LSS M: F ratio = 39: 38 LSS without spondylolisthesis (n=32) Age ± SD = 67.1 ± 9.8 yo LSS with fixed spondylolisthesis (n=22)	<u>**Physical factors**</u> ***Disability*** **Walking distance – SSSQ (total score: r=-0.50; p<0.001, physical function (r= -0.52; p<0.001), pain: r= -0.27; p=0.019, sensory: r=-0.36; p=0.002, neuroischemic: r= -0.30; p=0.009)** ***QoL*** **Walking distance – SF-36 physical functioning (r= 0.60; p<0.001)** **Walking distance – SF-36 (role physical: r= 0.35; p=0.003, bodily pain: r=0.39; p=0.001, general health**	<u>**Physical factors**</u> NA <u>**Psychological factors**</u> NA	<u>**Physical factors**</u> NA <u>**Psychological factors**</u> NA

		Age ± SD = 70.4 ± 10.9 yo LSS with mobile spondylolisthesis (n=23) Age ± SD = 68.6 ± 10.8 yo	**index: r=0.26; p=0.033 and social functioning: r=0.31; p=0.009)** **Walking distance – SF-36 (vitality (r= 0.24; p=0.041),** role emotional and mental health index subscales (r= [0.06 - 0.075] ; p>0.05) __Psychological factors__ NA		
Fujita et al. 2019	357	Patients who planned to undergo primary surgery for LSS with leg pain/NC M:F ratio= 201: 156 Age± SD = 73.3 ±5.47 yo	__Physical factors__ NA __Psychological factors__ NA	__Physical factors__ ***Disability*** **Short stride – JOABPEQ lumbar function <60 (OR=2.9 ; p<0.01)** **Short stride – score of walking ability in JOABPEQ <30 (OR=1.6 ; p=0.04)** **Short stride – score of social life in JOABPEQ <45 (OR=1.6 ; p=0.04)** **Short stride – score of psychological disorder in JOABPEQ <45 (OR=1.9 ; p<0.01)** **Short stride – symptom severity in ZCQ ≥4 (OR=1.8 ; p=0.03)** **Short stride – physical function in ZCQ ≥2.5 (OR=2.0 ; p<0.01)** **Short stride – motor deficit (OR=3.1 ; p<0.01)** **Short stride – sagittal vertical axis of ≥50 mm (OR=2.4)** __Psychological factors__ NA	__Physical factors__ NA __Psychological factors__ NA
Gaberlotti et al. 2014	14	Patients with LSS M:F ratio= 10: 4 Age ± SD = 74.5 ±9.8 yo	__Physical factors__ NA __Psychological factors__ NA	__Physical factors__ ***Pain*** **Post-effort pain perception – GDI (left side: r=-0.64; p<0.05 and right side: r=-0.53; p<0.05)** Pain perception pre-effort – kinematic parameters (speed, cadence, stride length, single stance, double stance, swing and trunk tilt) (r= [-0.45; 0.46] ; p>0.05) Pain perception post-effort – other kinematic parameters(speed, cadence, stride length, single or double stance, swing, trunk tilt, GDI) (r= [-0.42 - 0.19] ; p>0.05) __Psychological factors__ NA	__Physical factors__ NA __Psychological factors__ NA
Grelat et al. 2019	38	Patients with LSS referred to the neurosurgery department, with the ability to walk 10m or more without help M: F ratio= 23: 15	__Physical factors__ ***Disability*** **Measured walking perimeter – ODI (r= -0.44; p= 0.005)** Measured walking perimeter – QBPDS (r= -0.31; p= 0.06) ***QoL*** SF-12 – measured walking perimeter (p>0.05)	__Physical factors__ ***Disability*** **Free walking speed – ODI (r= -0.71; p=0.001)** **Free walking speed – QBPDS (r= -0.5; p= 0.0008)** __Psychological factors__ NA	__Physical factors__ NA __Psychological factors__ NA

		Age ± SD = 69.3 ±7.9 yo	**Psychological factors** NA		
Igawa et al. 2018	111	Patients with acquired degenerative LSS with leg pain M: F ratio= 65: 51 Age ± SD = 70.9 ±6.2 yo	**Physical factors** NA **Psychological factors** NA	**Physical factors** ***Objective measures*** **Anterior trunk flexion angle – step length (r=0.17; p=0.01)** **Anterior trunk flexion angle – maximum ankle plantar flexion moment (r=0.20; p<0.01)** Maximum trunk flexion angle – velocity or gait cycle time, maximum ankle dorsi flexion moment, maximum ankle plantar flexion angle, maximum ankle plantar flexion angle, maximum ankle power, and minimum ankle power (r=[-0.11 - 0.12] ; p>0.05) **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA
Inoue et al. 2020	183	Patients with LSS NC or radicular leg pain M:F ratio = 128: 55 Age = 70.5 yo (range 36-88 yo)	**Physical factors** ***Objective measures*** **Handgrip strength – walking time (r= -0.269 ; p<0.001)** **Handgrip strength – intermittent claudication (measure with the 300 m walking distance test) (r=0.201 ; p=0.008)** **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** ***Objective measures*** **Handgrip strength – walking (step) (r= -0.352 ; p<0.001)** **Psychological factors** NA
Ishimoto et al. 2012	1009	Total study Age ± SD = 66.3 ±13.6 yo *Group 1:* symptomatic LSS (N= 94) M:F =34:60	**Physical factors** ***Pain*** **Back and/or leg pain – 6-m walking time at maximal pace (OR = 1.17 ; p<0.05)** Back and/or leg pain – 6-m walking time at usual pace (OR=1.04 ; p>0.05) **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** ***Pain*** Back and/or leg pain – chair standing time (OR= 1.03 ; p>0.05) Back and/or leg pain – one-leg standing time (OR =1.00 ; p>0.05) **Psychological factors** NA
Kim et al. 2011	80	Patients with LSS with NC (n=40) M: F ratio= 11: 29 Age ± SD = 62.82 ±7.29 yo	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** ***Disability*** ODI – four functional mobility tests (alternative-step test, six-meter walk, sit-to-stand, timed-up and go) (p>0.05) **Psychological factors** NA
Kuittinen et al. 2014	14	Patients with LSS with leg pain and/or NC M:F ratio= 6: 8 Mean age = 58 yo (range 48-76)	**Physical factors** ***Objective measures*** MRI findings – walking distance (p>0.05) **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA
Kuwahara et al. 2019	29	Patients with LSS with leg pain and/or NC	**Physical factors** ***Pain***	**Physical factors** ***Pain*** **Leg pain changes – peak trunk tilt pre-effort (r=-0.455; p=0.044)**	**Physical factors** NA **Psychological factors**

		M: F ratio= 17: 12 *Group1* (n=8): leg pain and LBP changes Age ± SD = 72 ± 7 yo *Group2* (n=12): leg pain changes only Age ± SD = 69 ± 8 yo	<u>**Psychological factors**</u> NA	Leg pain changes – velocity, peak trunk tilt post effort, peak thoracic tilt, peak lumbar tilt and peak pelvis tilt (r= [-0.206 - 0.286] ; p>0.05). **Low back pain changes – peak lumbar tilt pre-effort (r=-0.508; p=0.022)** **Low back pain changes – peak lumbar tilt post-effort (r=-0.503; p=0.024)** **Low back pain changes – pelvis variation (r=0.506; p=0.023)** Low back pain change - velocity, peak trunk tilt, peak thoracic tilt, changes in lumbar spine and peak pelvic tilt pre- and post-effort (r= [-0.274 - 0.343] ; p>0.05) <u>**Psychological factors**</u> NA	NA
Minetama et al. 2020	71		<u>**Physical factors**</u> ***Objective measures*** **Daily step count – walking distance (r=0.338 ; p<0.05)** <u>**Psychological factors**</u> NA	<u>**Physical factors**</u> NA <u>**Psychological factors**</u> NA	<u>**Physical factors**</u> ***Pain*** NRS (LBP, leg pain, leg numbness) – daily step count (r = [-0.200 - -0.003] ; p>0.05) ***Disability*** ZCQ (symptom severity, physical function) – daily step count (r=[-0.218 - -0.215] ; p>0.05) <u>**Psychological factors**</u> **PASS-20 (total score, cognitive anxiety, escape/avoidance, fear) – daily step count (r = [– 0.352 – 0.338 ; p<0.05)** PASS-20 (physiological anxiety) – daily step count (r = -0.229 ; p=0.055) **HADS depression score – daily step count (r = – 0.245 ; p<0.05)** HADS anxiety – daily step count (r = – 0. ; p=0.499) PCS (total score, rumination, magnification, helplessness) – daily step count (r= [-0.189 - -0.137]; p>0.05) TSK-11 – daily step count (r= -0.229 ; p=0.055)
Nagai et al. 2014	11	Patients with LSS with NC M: F ratio= 8: 3 Age ± SD = 72.8 ± 5.5 yo	<u>**Physical factors**</u> ***Other objective measures*** **RMS at the cervical sensor – walking distance (r=-0.64; p=0.03)** RMS at the lumbar sensor – walking distance (r=-0.55 ; p>0.05) Stride frequency – walking distance (r=0.43 ; p>0.05) <u>**Psychological factors**</u> NA	<u>**Physical factors**</u> NA <u>**Psychological factors**</u> NA	<u>**Physical factors**</u> NA <u>**Psychological factors**</u> NA
Özdermir et al 2015	108	*Group 1* (n=54): Patients with diagnosis of LSS by clinical findings and MRI M: F ratio = 9: 45 Age ± SD = 68.06 ± 9.55 yo	<u>**Physical factors**</u> ***QoL*** **Walking capacity – SF-36 total score (r= 0.458; p<0.05)** **Walking capacity – SF-36 physical health (r= 0.476; p<0.001)** **Walking distance – SF-36 mental health (r= 0.319; p<0.05).**	<u>**Physical factors**</u> NA <u>**Psychological factors**</u> NA	<u>**Physical factors**</u> NA <u>**Psychological factors**</u> NA

			<u>Psychological factors</u> NA		
Pryce et al. 2012	33	Patients with LSS with NC M: F ratio = NA Age ± SD = 68.5 ± 8.4 yo	**<u>Physical factors</u>** NA **<u>Psychological factors</u>** NA	**<u>Physical factors</u>** NA **<u>Psychological factors</u>** NA	**<u>Physical factors</u>** ***Pain*** **PA volume – back pain (intensity and function) and leg pain (function) (r = [-0.44 – -0.42] ; p<0.05)** **PA duration – back pain (intensity and function) and leg pain (function) (r=[-0.42 – -0.38] ; p<0.05)** PA intensity – back and leg pain (intensity and function) (r=[-0.25 – -0.18] ; p>0.05) <u>Ambulatory behavior meaningful intensity:</u> **Bout length – back pain (r=-0.36 ; p<0.05)** Bout length – back pain (function) and leg pain (intensity and function) (r=[-0.31 – -0.14] ; p>0.05) **Maximum bout length – back pain (intensity and function) and leg pain (function) (r= [-0.43 – -0.29] ; p<0.05)** Maximum bout length – leg pain intensity (r=-0.21 ; p>0.05) <u>Ambulatory behavior moderate intensity:</u> **Bout length – leg pain intensity (r=-0.35 ; p<0.05)** Bout length – back pain (intensity and function) and leg pain (function) (r=[-0.30 – -0.23] ; p>0.05) **Maximum bout length – leg pain intensity (r=-0.39 ; p<0.05)** Maximum bout length – back pain (intensity and function) and leg pain (function) (r=[-0.34 – -0.30] ; p>0.05) <u>Sedentary behavior:</u> Duration, bout length and maximum bout length – back and leg pain (intensity and function) (r=[-0.24 – 0.26] ; p>0.05) ***Disability*** **PA (volume, intensity, duration) – ODI (r=[-0.52 – -0.35] ; p<0.05)** **PA (volume, intensity, duration) – RMDQ (r=[-0.58 – -0.42] ; p<0.05)** **PA (volume, intensity, duration) – DASH (r=[-0.57 – -0.49] ; p<0.01)** <u>Ambulatory behavior meaningful intensity:</u> Bout length – ODI (r=-0.30 ; p>0.05) **Maximum bout length – ODI (r=-0.46 ; p<0.01)** **Bout length and maximum bout length – RMDQ (r=[-0.50 – -0.38] ; p<0.05)** **Bout length and maximum bout length – DASH (r=[-0.51 – -0.46] ; p<0.01)** <u>Ambulatory behavior moderate intensity:</u> **Bout length – ODI (r=-0.49 ; p<0.01)** **Maximum bout length – ODI (r=-0.55 ; p<0.01)** **Bout length and maximum bout length – RMDQ (r=[-0.50 – -0.38] ; p<0.05)** Bout length – DASH (r=-0.26 ; p>0.05) **Maximum bout length – DASH (r=-0.38 ; p<0.05)**

					Sedentary behavior behavior: Duration, bout length and maximum bout length – ODI (r=[-0.14 – 0.30] ; p>0.05) Duration, bout length and maximum bout length – RMDQ (r=[-0.10 – 0.32] ; p>0.05) Duration, bout length and maximum bout length – DASH (r=[0.12 – 0.22] ; p>0.05) ***QoL*** **PA (volume, duration) – SF-36 (total, PH, MH, PF, BP)(r=[0.35 – 0.64] ; p<0.05)** **PA (intensity) – SF-36 (total, PH, MH, PF)(r=[0.36 – 0.55] ; p<0.05)** PA (intensity) – SF-36 BP (r=0.21 ; p>0.05) Ambulatory behavior meaningful intensity: **Bout length and maximum bout length – SF-36 (total, PH, MH, PF, BP) (r=[0.34 – 0.73] ; p<0.05)** Ambulatory behavior moderate intensity: **Bout length – SF-36 (total, PH, PF, BP) (r[=0.35 – 0.59] ; p<0.05)** Bout length – SF-36 MH (r=0.32 ; p>0.05) **Maximum bout length – SF-36 (total, PH, MH, PF) (r=[0.39 – 0.61] ; p<0.05)** Maximum bout length – SF-36 BP (r=0.33 ; p>0.05) Sedentary behavior behavior: Duration, bout length and maximum bout length – SF-36 (total, PF, MH, PF, BP) (r=[-0.24 – 0.01] ; p>0.05) **Bout length – SF-36 PF (r= -0.41 ; p<0.05)** Bouth length – SF-36 (total, PH, MH, BP) (r=[-0.32 – -0.20] ; p>0.05) **Psychological factors** NA
Quack et al. 2019	67	Patients with degenerative LSS M: F ratio = 34: 33 Age ± SD = 62.5 ± 11.7 yo	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA ***Anxiety, fear avoidance and depression*** **AAPI participation scale – DESC (r= -0.57 ; p<0.01)** **RehaCAT lower extremity – DESC (r=0.43 ; p<0.01)** **RehaCAT activities of daily living – DESC (r=0.45 ; p <0.01)** **AAPI participation – TSK SF (r=-0.39 ; p<0.01)** AAPI participation – TSK AA (r=-0.25 ; p>0.05) **RehaCAT lower extremity – TSK SF (r=0.52 ; p <0.01)** **RehaCAT lower extremity – TSK AA (r=0.45 ; p <0.01)** **RehaCAT activities of daily living – TSK SF (r=0.43 ; p <0.01)** **RehaCAT activities of daily living – TSK AA (r=0.44 ; p <0.01)**
Schmidt et al. 2017a	300	Patients with LSS *Group1* (n=54): Patients with symptomatic LSS	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** ***Objective measures*** **Trunk extensor muscle endurance, leg strength asymmetry and leg speed – SPPB score (r^2= 0.24)**

		Age ± SD = 76.9 ± 6.6 yo *Group2* (n=246): Patients with no symptomatic LSS Age ± SD = 77.1 ± 7.2 yo			**Trunk extensor muscle endurance, knee flexion ROM and knee extension asymmetry – HGS (r^2= 0.35)** **Leg strength – Chair Stand test (r^2= 0.19)** **Psychological factors** NA
Sigmundsson et al. 2011	109	Patients with a central spinal stenosis planned for surgery M:F ratio = 53: 56 Age ± SD = 71 ± 10 yo	**Physical factors** ***MRI findings*** Estimated walking distance – MRI findings (r = -0.01 ; p>0.05) Estimated walking distance – Multilevel spinal stenosis (r = -0.02 ; p>0.05) **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA
Thornes et al. 2018a	103	Patients with a symptomatic and radiological verified central spinal stenosis M:F ratio = 48: 55 Age ± SD = 71.3 ±7.3 yo	**Physical factors** ***Disability*** **Tandem walk – SSSQ functional scale (r= -0.29; p= 0.01)** Tandem walk – SSSQ symptoms scale (r=-0.20 ; p>0.05) **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** ***Disability*** **30-s SS – SSSQ (symptoms scale: r= -0.29; p= 0.01), function scale: r=-0.44 ; p<0.01)** **Stair climb – SSSQ (symptoms scale : r= 0.40; p=0.01, function scale: (r= 0.58; p=0.01)** **OLS – SSSQ (symptoms scale : r= -0.33; p=0.01, function scale: r= -0.28; p=0.01)** **Psychological factors** NA
Thornes et al. 2018b	62	Patients with MRI-verified LSS M: F ratio = 33: 29 Age ± SD = 71.2 ± 7.1 yo	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** ***Disability*** **Mini-BESTest – SSSQ function scale (b= -0.1; p= 0.042**) **Stability in Gait – ODI (b= -5.3; p=0.001)** Mini-BESTest – ODI (b = -0.9 ; p>0.05) **Psychological factors** NA
Tomkins-Lane, 2013	49	Patients with LSS with NC or walking limitations M: F= 25: 24 Age ± SD = 65.8 ±10.0 yo	**Physical factors** ***Pain*** **Walking capacity – years of back pain (r=0.29; p<0.05)** **Walking capacity – years of leg pain (r=0.42; p<0.01)** **Walking capacity – pre-walk leg VAS (r=-0.32; p<0.05)** **Walking capacity – HUI Q8 (r=-0.35; p<0.05)** **Walking capacity – HUI Q15 (r=-0.33; p<0.05)** ***Disability*** **Walking capacity – SSSQ symptom scale (r=-0.28; p<0.05)** **Walking capacity – ODI (r=0.52; p<0.01)** ***QoL*** **Walking capacity – HUI score (r=0.38; p<0.05)**	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA

			Other objective measures **Walking capacity – balance problems (r=-0.40; p<0.01)** **Psychological factors** NA		
Tong et al. 2007	48	*Group 1* (n=24): Patients with lumbar spinal stenosis M: F 14: 10 Age ± SD = 68.6 ± 6.8 yo	**Physical factors** ***Pain*** 15-min walk test – PDI (β= -0.12 ; p>0.05) 7-day walking distance – PDI (β=0.23 ; p>0.05) ***Disability*** 15-min walk test – QBPDS (β=-0.17 ; p>0.05) 7-day walking distance – QBPDS (β=0.05 ; p>0.05) **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA
Zeifang et al. 2008	63	Patients with symptomatic LSS (N=63) M:F ratio = 26: 37 Age (median) = 68 yo (13 IR)	**Physical factors** ***MRI findings*** **Walking capacity – MRI findings (tau b=-0.118; p=0.032)** ***Other objective measures*** Walking capacity – BMI (tau b= -0.194; p=0.025) Walking capacity – functional status (tau b=0.225; p=0.011) **Psychological factors** ***Anxiety and depression*** Walking capacity – CES-D (tau b = -0.053 ; p>0.05)	**Physical factors** NA **Psychological factors** NA	**Physical factors** NA **Psychological factors** NA

M= male, F= female, SD = standard deviation, BMI = Body mass index, LSS= Lumbar Spinal Stenosis, NC= Neurogenic Claudication, ODI= Oswestry Disability Index, NRS= Numeric Rating Scale, SF-12= Medical Outcomes Short-Form 12, SPWT= Self-Paced Walking Test, QBPDS= Quebec Back Pain Disability Scale, SSSQ= Swiss Spinal Stenosis Questionnaire, SF-36= 36-item Short Form Health Survey, PH = Physical Health, MH = Mental Health, PF = Physical Function, BP = Bodily Pain, JOABPEQ= Japanese Orthopedic Association Back Pain Evaluation Questionnaire, ZCQ= Zurich Claudication Questionnaire, PASS-20 = Pain Anxiety Symptoms Scale, PCS = Pain Catastrophizing Scale, TUGT= Timed Up-and-Go Test, GDI= Gait Deviation Index, VAS= Visual Analog Scale, MRI= Magnetic Resonance Imaging, BDI= Beck Depression Inventory, EMG= Electromyography, RMS= Root Mean Square, HADS= Hospital Anxiety and Depression Scale, RMDQ = Roland-Morris Disability Questionnaire, DASH= Disability of the Arm, Shoulder and Hand questionnaire, ROM= Range of Motion, HGS= Habitual Gait Speed, DESC= Rasch-based Depression Screener, TSK= Tampa Scale of Kinesiophobia, AA= Activity Avoidance, SF= Somatic Focus, ADL=Activity of Daily Living, RehaCAT = Rasch-based RehaCAT-system, PI-G= Pain Interference Scale-German, SPPB= Short Physical Performance Battery, OLS= One Leg Stance test, 30-s SS= 30 seconds Sit to Stand, HSCL25= Hopkins symptom check list, HUI= Health Utilities Index Mark 3, PDI= Pain Disability Index, CES-D= Center of Epidemiological Studies Depression Scale, OR = Odds Ratio

Annexe E – Article 1, Non-significant associations (Supplement Material 4)

Supplement 4: Non-significant associations reported in the 24 included studies.

Walking Capacity

PROMS

Pain

Conway et al. 2011 reported no significant correlation between leg pain severity and walking distance to first symptoms or total walking distance and Tong et al. 2007 reported no significant correlation when walking capacity measured with the 15-min walking test of the 7-day walking test [1, 2]. Ishimoto reported no significant association between back or leg pain and walking time at usual pace [3].

Disability

Two studies reported that there is no correlation between the total QBPDS score and walking distance [2, 4].

In the study of Conway and colleagues, the subscale "stand" was not significantly correlated to the total walking distance [1].

One study did not report a significant correlation between SSSQ physical function and symptoms subscales and distance to first symptoms measured with the Self-Paced Walking Test (SPWT) [1]. In addition, the symptom subscale of the SSSQ did not seem to be correlated with walking capacity when measured using the tandem walk test [5].

Conway et al. 2011 showed no significant correlation between walking distance to first symptoms and disability using the ODI [1].

Quality of life

One study using the SF-12 showed that the total walking perimeter was not correlated to this shorter version of the questionnaire [4]. In addition, walking distance before the first symptoms was not correlated with the PF subscale [1]. One study showed a non-significant correlation between mental health subscale and walking distance [6].

Objectives measures

MRI findings

Results showed that there was no significant correlation between measured or estimated walking distance and MRI findings such as severity of the entrance stenosis, mid zone, entrance zone width, mid zone area, dural sac area, or the number of levels with stenosis [7, 8].

Other Objectives Measures

One study showed that there was no significant correlation between activity (count per day) and walking capacity [1].

Another study did not show significant correlations with lumbar postural sway, autocorrelation coefficient for both cervical and lumbar sensors position and stride frequency [9].

Another study showed that there were no correlations between estimated walking distance and the minimal dural sac area, multilevel stenosis and low-grade spondylolisthesis [8] .

Gait pattern characteristics

PROMS

Pain severity

When assessing pain with the VAS, no correlation was found between pain and gait patterns characteristics [10, 11]. However, pain location in the study of Gaberlotti and colleagues was not defined. It was not possible to identify if pain perception was about back, leg or global pain [10]. Also, there was no significant correlation between pain perception pre-walking and kinematic parameters such as stride length, single stance, double stance, swing and trunk tilt or between leg pain changes and peak trunk tilt post effort, trunk changes, peak thoracic tilt, peak lumbar tilt and peak pelvic tilt [10, 11]. Moreover, there was no significant correlation between low back pain change and peak trunk tilt, peak thoracic tilt, variation of lumbar spine tilt and peak pelvic tilt pre- and post-effort [11].

Pain severity assessed using NRS was not significantly correlated to step length, lumbar ROM and lumbar proprioception. Cadence was not associated with pain regardless of the tool used [12].

Objectives Measures

There were no significant correlations between maximum trunk flexion angle and velocity or gait cycle time, maximum ankle dorsi flexion moment, maximum ankle plantar flexion angle, maximum ankle plantar flexion angle, maximum ankle power, and minimum ankle power [13].

Functional task

PROMS

Pain

There were no significant correlations between back or leg pain intensity and physical activity intensity [14].

There were no significant association between the function scale and the four control systems in balance control (anticipatory postural adjustments, reactive responses, sensory orientation and stability in gait) measured with the 14 tasks from the Mini-BESTest [15].

One study reported no significant association between pain (back, leg and numbness) and daily step count (MINE).

Disability

Most of the QBPDS subscales (total, stand, walk, reach and groceries) were not significantly correlated with activity count per day and time of continuous activity [1].

One study reported no association between the ZCQ also known as the SSSQ and daily step count [16].

Two studies did not show significant correlations between the ODI and functional task measured using activity count per day, maximum of continuous activity and the four functional mobility tests (Alternative-Step Test, 6-Meter-Walk Test, Sit-to-Stand test and Timed Up and Go test) [1, 17].

Quality of life

Two studies showed that the SF-36 was not correlated with activity count per day and maximum time of continuous activity as well as bout length (only mental health subscale) and maximum bout length (only bodily pain subscale) at moderate intensity [1, 14].

Depression and fear avoidance

Regarding results of Quack and colleagues, there were no significant correlations between participation and the activity avoidance subscale of the TSK [18].

Minetama and colleagues reported no significant correlation between daily step count and anxiety, and pain catastrophizing [16].

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Annexe F – Article 1, Walking tests (Supplement Material 5)

Tests used to assess walking capacity

The assessment of walking capacity (walking time or distance) was conducted using highly heterogeneous tests across the included studies. For this reason, we decided to look at the validity and reliability of these different walking tests in the LSS population.

Table 1: Validity and reliability of walking tests

Walking Test	SPWT (30 min)	SPWT (15 min)	SWT	TWT (0-1000m)	TWT (20 min)	6-MWT	SMWT	50-meter walkway	Tandem Walk (2m)
Validity	✔	?	X	X	X	?	✔	X	X
Reliability	✔	?	✔	X	✔	✔	✔	X	X

SPWT= Self-Paced Walking Test, SWT= Shuttle Walking Test, TWT= Treadmill Walking Test, 6-MWT= 6-Minute Walking Test, SMWT= Six Meters Walk Test

Most of the walking tests used were not validated in individuals with symptomatic LSS. However, several were at least validated in elderly.

Validity and/or reliability

SPWT (30 min): (Rainville et *al.* 2012; Tomkins-Lane et *al.* 2009)

SWT: (Pratt et *al.* 2002)

TWT: (20 min): (Deen et *al.* 2000)

6-MWT: (Harada, Chiu and Stewart, 1999)

SMWT: (Kim et *al.* 2011)

Annexe G - Article 2, Appendix 1

Appendix. Definition of gait pattern characteristics

Gait parameters	Definition
General gait parameters	
Cycle duration (s)	Time between two consecutives heel touching the ground for a same foot.
Cadence (steps/min)	Number of gait cycles in a minute.
Stride length (m)	The distance between heels of two consecutives footprints for the same foot.
Stride velocity (m/s)	Forward speed of one gait cycle.
Temporal gait parameters	
Stance phase (%)	The percentage of time during which the foot is touching the ground during a gait cycle.
Loading (%)	The percentage of time during the stance phase between the heel strike and the foot being flat on the ground.
Foot-flat (%)	The percentage of time during the stance phase when the foot is flat on the ground.
Pushing (%)	The percentage of time during the stance phase between the foot being flat on the ground and the toe leaving the ground.
Swing phase (%)	The percentage of time during which the foot is not touching the ground during a gait cycle.
Double support (%)	The percentage of time during which both feet are touching the ground during a gait cycle.
Spatial parameters	
Peak angular velocity (°/s)	The maximum angular velocity of the foot during the swing, between max heel clearance and min toe clearance.
Strike angle (°)	The angle between the foot and the ground during heel strike.
Lift-off angle (°)	The angle between the foot at the end of the push phase and the ground.
Clearance parameters	
maxHC (m)	Maximal height above the ground reached by the heel during each gait cycle.
minTC (m)	Minimum height of the toes during swing phase.

Annexe H – Article 3, Appendix 1

Appendix 1. ANCOVAs

This appendix contains all ANCOVAs conducted using age, sex, height and weight as covariables.

General parameters of gait

1. Cycle duration

	Degrees of Freedom	Mean Square	F	p-value	η^2
Age	1	0.018	0.467	0.496	0.004
Height	1	0.041	1.060	0.305	0.008
Weight	1	7.207E-05	0.002	0.966	0.000
Sex	1	0.096	2.457	0.119	0.019
Group	1	0.832	21.312	<0.001	0.143

2. Cadence

	Degrees of Freedom	Mean Square	F	p-value	η^2
Age	1	25.838	0.206	0.651	0.002
Height	1	31.191	0.249	0.619	0.002
Weight	1	8.922	0.071	0.790	0.001
Sex	1	526.844	4.205	0.042	0.032
Group	1	3623.606	28.919	<0.001	0.184

3. Stride length

	Degrees of Freedom	Mean Square	F	p-value	η^2
Age	1	0.208	9.234	0.003	0.067
Height	1	0.087	3.881	0.051	0.029

Weight	1	0.058	2.595	0.110	0.020
Sex	1	0.052	2.324	0.130	0.018
Group	1	01.481	65.853	<0.001	0.340

4. **Speed**

	Degrees of Freedom	Mean Square	F	p-value	η^2
Age	1	0.394	9.339	0.003	0.068
Height	1	0.039	0.916	0.340	0.007
Weight	1	0.084	1.985	0.161	0.015
Sex	1	1.880E-5	0.000	0.983	0.000
Group	1	2.676	63.485	<0.001	0.332

<u>Temporal parameters of gait</u>

1. **Stance phase**

	Degrees of Freedom	Mean Square	F	p-value	η^2
Age	1	0.700	0.115	0.735	0.001
Height	1	26.063	4.298	0.040	0.032
Weight	1	22.498	3.710	0.056	0.028
Sex	1	0.011	0.002	0.965	0.000
Group	1	69.758	11.504	<0.001	0.082

2. **Loading**

	Degrees of Freedom	Mean Square	F	p-value	η^2
Age	1	10.198	1.324	0.252	0.010
Height	1	0.012	0.002	0.968	0.000
Weight	1	8.080	1.049	0.308	0.008

Sex	1	20.567	2.671	0.105	0.020
Group	1	49.452	6.421	0.012	0.048

3. Foot-flat

	Degrees of Freedom	**Mean Square**	**F**	**p-value**	**η²**
Age	1	399.893	9.994	0.002	0.072
Height	1	14.766	0.369	0.545	0.003
Weight	1	89.850	2.245	0.136	0.017
Sex	1	1.586	0.040	0.843	0.000
Group	1	1033.32	25.824	<0.001	0.168

4. Pushing

	Degrees of Freedom	**Mean Square**	**F**	**p-value**	**η²**
Age	1	141.440	5.996	0.016	0.045
Height	1	6.532	0.276	0.601	0.002
Weight	1	83.398	3.518	0.063	0.027
Sex	1	38.549	1.626	0.205	0.013
Group	1	779.157	32.865	<0.001	0.204

5. Double support

	Degrees of Freedom	**Mean Square**	**F**	**p-value**	**η²**
Age	1	8.301	0.484	0.488	0.004
Height	1	153.577	8.961	0.003	0.066
Weight	1	116.419	16.793	0.010	0.051
Sex	1	9.868	0.576	0.449	0.005
Group	1	324.244	18.918	<0.001	0.130

6. Swing

	Degrees of Freedom	Mean Square	F	p-value	η²
Age	1	2.521	0.420	0.518	0.003
Height	1	26.664	4.440	0.037	0.034
Weight	1	22.222	3.701	0.057	0.028
Sex	1	0.017	0.003	0.958	0.000
Group	1	72.991	12.155	<0.001	0.087

Spatial parameters of gait

1. Peak angular velocity

	Degrees of Freedom	Mean Square	F	p-value	η²
Age	1	38519.923	13.998	<0.001	0.099
Height	1	1862.663	0.677	0.412	0.005
Weight	1	68.113	0.025	0.875	0.000
Sex	1	201.779	0.073	0.787	0.001
Group	1	117452.487	42.682	<0.001	0.250

2. Heel-strike pitch angle

	Degrees of Freedom	Mean Square	F	p-value	η²
Age	1	226.049	9.993	0.002	0.072
Height	1	27.967	1.236	0.268	0.010
Weight	1	1.076	0.048	0.828	0.000
Sex	1	153.828	6.801	0.010	0.050
Group	1	578.268	25.564	<0.001	0.166

3. **Toe-off pitch angle**

	Degrees of Freedom	Mean Square	F	p-value	η^2
Age	1	219.177	3.537	0.062	0.027
Height	1	1.644	0.027	0.871	0.000
Weight	1	39.875	0.644	0.424	0.005
Sex	1	5.493	0.089	0.766	0.001
Group	1	3310.923	53.432	< 0.001	0.293

Clearance parameters of gait

1. **Minimum toe clearance**

	Degrees of Freedom	Mean Square	F	p-value	η^2
Age	1	0.001	8.430	0.004	0.062
Height	1	0.000	2.478	0.118	0.019
Weight	1	7.051E-6	0.085	0.771	0.001
Sex	1	1.509E-6	0.018	0.893	0.000
Group	1	5.813E-5	0.701	0.404	0.005

Annexe I – Article 5, Supplementary file #1: Content of education sessions

<table>
<tr><th>First session</th><th>Second session</th></tr>
<tr><td>

Definition of lumbar spinal stenosis and etiologies

Definition and description of degenerative lumbar spinal stenosis and congenital lumbar spinal stenosis
Pathophysiology of degenerative lumbar spinal stenosis
Prevalence of degenerative lumbar spinal stenosis

Symptoms manifestation of degenerative lumbar spinal stenosis

Symptoms description and localisation
Explication of the mechanisms of neurogenic claudication

What is the neurogenic claudication
Relation between neurogenic claudication and lumbar posture

Diagnosis and natural history of lumbar spinal stenosis

How it is diagnosed (patients’ history, medical imaging (e.g., IRM) and physical assessment)
How degenerative lumbar spinal stenosis evolves over time

Time allocated for patients' questions
</td><td>

Advice on posture

Why pain is increased by trunk extension and why it is alleviated by sitting or bending forward
Posture during sleep

Relation between lumbar spinal stenosis and quality of life

How it can affect emotions, kinesiophobia and quality of life

Importance of walking

Walking for the maintenance of autonomy
How walking can be adapted

Physical activity recommendations

Treatment options and recommendations

Exercise, Education
Manual therapy
Injection and surgery

Time allocated for patients' questions
</td></tr>
</table>

Annexe J – Article 5, Supplementary file #2: Exercises

Note: All exercises could be adapted based on patients' physical capacities and symptoms intensity. The sets, repetitions, and tempo were determined by the kinesiologist supervising the sessions based on the patients' physical abilities.

1. **<u>Warm-up</u>**

Option 1	**Option 2**	**Option 3**
Stationary bike 	Treadmill walking 	Free walking 
Warm up for 3 to 5 minutes. Split it up if needed if pain prevents continuous warming up		

2. Strengthening

Exercise #1

Level 1	Level 2	Level 3
Pelvic tilts on an exercise ball	Pelvic tilts in a lying position	Pelvic tilts against the wall
		

Exercise # 2 : squat

Level 1	Level 2	Level 3	Level 4	Level 5
Partial squat with hand support	Sit-to-stand with support	½ squat	Sit-to-stand without support	Wall ball squat
				

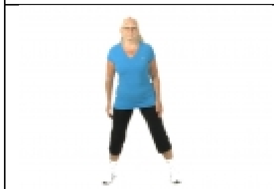
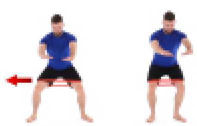
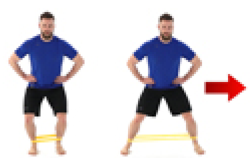
Exercise # 3 : bird dog

Level 1	Level 2	Level 3	Level 4	Level 5
Standing bird dog (alternating)	Standing bird dog	Bird dog (alternating)	Bird dog	Plank on hands with lifting one leg
				

Exercise #4 : bridge

Level 1	Level 2	Level 3	Level 4	Level 5
Half glute bridge	Glute bridge	Glute bridge with feet on an unstable surface	Glute bridge, lifting one leg	Single-leg glute bridge descent
				

Exercise # 5 : Hip abduction

Level 1	Level 2	Level 3	Level 4	Level 5
ABD – lateral movements	ABD – lateral movements with a resistance band around the thighs	ABD – lateral movements with a resistance band around the ankles	Standing ABD with support	Standing ABD with a resistance band around the ankles
				

3. Balance

Static

Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Semi-tandem	Tandem	Single-leg balance with eyes open	Single-leg balance with eyes closed	Balance on an unstable surface
				

Dynamic

Varied circuit including walking. Example: overcoming obstacles or avoiding obstacles or changes in direction.

4. Stretching

Option 1	**Option 2**	**Option 3**
 Seated hamstring stretch	 Standing hamstring stretch	 Lying hamstring stretch
 Standing hip flexor stretch	 Lying hip flexor stretch	 Hip flexor stretch using a chair
 glute stretch (varying leg height for more difficulty)		