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In Situ mechanical effects of a specific neurodynamic mobilization of the superficial fibular nerve: a cadaveric study

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Mechanical Effects of a Specific Neurodynamic Mobilization of the Superficial Fibular Nerve: A Cadaveric Study

Abstract

Context: A specific neurodynamic mobilization for the superficial fibular nerve (SFN) has been suggested in the reference literature for manual therapists to evaluate nerve mechanosensitivity in patients. However, no biomechanical studies examined the ability of this technique to produce nerve strain. Therefore, mechanical specificity of this technique is not yet established.

Objective: The aim of our study was to test whether this examination and treatment technique was producing nerve strain in the fresh frozen cadaver and the contribution of each motion to total longitudinal strain.

Design: Quantitative original research, controlled laboratory study

Methods: A differential variable reluctance transducer was inserted in ten SFN from six fresh cadavers to measure strain during the mobilization. A specific sequence of plantar flexion (PF), ankle inversion (INV), straight leg raise (SLR) position and 30{degree sign} of hip adduction (ADD) was applied to the lower limb. The mobilization was repeated at 0°, 30°, 60° and 90° of Straight Leg Raise (SLR) position to measure the impact of hip flexion position.

Findings: Compared to a resting position, this neurodynamic mobilization produced a significant amount of strain in the SFN (7.93% ± 0.51 $P < 0.001$). PF (59.34% ± 25.82) and INV (32.80% ± 21.41) accounted for the biggest proportion of total strain during the mobilization. No significant difference was reported between different hip flexion positions. Hip ADD did not significantly contribute to final strain (0.39% ± 10.42 $P > 0,05$) although high subject variability exists.

Conclusion: Ankle motions should be considered the most important during neurodynamic assessment of the SFN for distal entrapment. These results suggest that this technique produces sufficient strain in the SFN and could therefore be evaluated In Vivo for correlation with mechanosensitivity

Introduction

Neurodynamic mobilizations are a range of different techniques clinically used to test a patient's nerves mechanical and symptomatic response to movement.[1] Passive mobilizations and sensitizing movements[2, 3] are used to induce strain in nerves using to assess the relevant nerve mechanosensitivity to these induced forces. Mechanosensitivity refers to the relative sensitivity of the nerve of interest when exposed to external force/loads and is thought to be a protective mechanism from mechanical stress of the nerve[2] that may demonstrate pathological changes within its tissue.[4] Heightened mechanosensitivity is considered an abnormal response during neurodynamic evaluation by clinicians.[5, 6]

Superficial fibular nerve (SFN) entrapment neuropathy is a condition where the SFN experiences a prolonged mechanical compression at the subcutaneous exit point by the crural fascia.[7] Emerging from the lumbo-sacral L4 through S3, the sciatic nerve courses along the posterior aspect of the thigh and splits at the popliteal level to form the tibial (medial) and common fibular nerve (lateral). The SFN (roots L4-S1) originates from the common fibular nerve along the proximal insertions of the fibularis longus muscle and exits the crural fascia at the distal 1/3 of the lower leg. Symptoms of SFN entrapment include pain and/or paresthesia on the antero-lateral aspect of the leg and to the latero-dorsal aspect of the foot,[8, 9] except between the two first toes. A prevalence of 3.5% of SFN entrapment neuropathy at the exit from the crural fascia in patients with chronic leg pain was previously reported.[10]Additionally, Falciglia et al. reported SFN entrapment neuropathy in 4.1% of severe ankle sprains in children and adolescents.[11] Conservative options in the management of peripheral neuropathies, such as physical rehabilitation, are often recommended before referral to physicians who specialize in pain managment.[12, 13] Within the modalities used by manual therapists, neurodynamic mobilizations (NDM) were reported as effective in the management of peripheral neuropathies,[14, 15, 16] cervical radiculopathies, and low back pain although more robust evidence is yet to be published.[17]

Previously, authors reported that neural tissue responds to movement by strain and excursion[2, 5]. Changes in nerve strain are known to be influenced by joint position,[17,18] surgery[19] and injury.[20] Moreover, many authors have reported the contribution of lower limb movement on tibial and sciatic nerve strain during the Straight Leg Raise (SLR) test combined with ankle dorsiflexion.[18, 21, 22] Çelebi et al[23] conducted a sonoelastographic investigation and showed an increase in sciatic nerve stiffness at the gluteal region in patients with lumbar disc herniation. Additionally, Neto et al[24] has also shown a reduction in nerve stiffness immediately following NDM in a static slump position in patients affected by sciatica.[24] These results are however contradictory compared to a previous study using a long-sitting slump position. This suggests clinicians must investigate neuropathic pain with different techniques to find the most appropriate type of mobilization for the patient.[24]

Additionally, due to the poor efficiency of the lymphatic system for drainage, chronic local oedema and intra-neural fluid accumulation within the nerve may lead to fibrosis impairing the ability of nerve to glide freely[25, 26] thereby impairing the stretch response of the nerve and its normal physiological functions.[25, 27, 28] Strain can play a role in nerve physiology. Following their investigation, authors found that strain of 15.7% or more applied to a nerve in the rabbit sciatic nerve was enough to cause an interruption of the neural vascularization.[29] Brown et al[30] studied in-vitro the mobilizations impact on intra-neural fluid dispersion at the tibial nerve and reported that a mechanical influence in the form of passive mobilization of the ankle would provide a dispersion effect on intra-neural fluid. Moreover, Boudier-Revéret et al[31] stated that strain and fluid dispersion may not strongly correlate after they demonstrated that sliding and tensioning neural mobilization techniques did not show a significant difference in intra-neural fluid dispersion between the two techniques. The finding could demonstrate this importance of general movement and mobilization techniques on fluid dispersion

Although NDM are commonly used by manual therapists, lack of standardization in the application of neurodynamic tests makes the clinical effects of NDM hard to evaluate.[32] Specific NDM with SFN bias is, for the moment, based on neurodynamics reference books[33] (Butler, 1991) and anecdotal evidence.[34] There is no evidence emerging from the literature as to whether these proposed techniques produce nerve elongation and the magnitude of it. This could have a significant clinical impact as the sequence used to evaluate neural mechanosensitivity may not be the most efficient at eliciting or reproducing patient's symptoms thereby leading to inconclusive findings from the test. Previous authors have identified hip flexion as an important influencer of strain measured at the tibial nerve.[18] This could indicate an important impact of hip position during NDM with SFN bias as a sensitizing motion. There is, to our best knowledge, no authors that have studied the biomechanical influence of hip position in the frontal plane on lower limb neurodynamics for the SFN.

Therefore, the purpose of this study was to examine if NDM with SFN bias[33] produces longitudinal strain at the exit of the SFN from the crural fascia and quantify the strain behavior of the SFN throughout the mobilization. The first objective was to compare the effect of four different hip positions (as used during a SLR test) on total strain following a complete mobilization. We hypothesized that applying a neurodynamic test at 90° of hip flexion during the

SLR would produce the most strain at the SFN. The second objective was to describe the contribution of each motion comprised in the mobilization sequence to total strain. We hypothesized that the Adduction (ADD) component of the NDM might lower the strain experienced by the SFN because of the medial route of the lumbar plexus in regards of the abduction ABD/ADD axis of the hip. While it has been reported that neighboring joints seem to have a great influence on nerve strain during NDM, ankle motions may have the biggest contribution on total nerve strain. The results of this study may help to better understand the mechanical behavior of the SFN during NDM and could support the use of this NDM for further *in vivo* studies.

1. Materials and methods

Specimens

Six fresh frozen cadavers from XXX anatomy laboratory were selected for this study, four females and two males were selected for this study (mean age of 84 ± 4.33 years, body mass index 21.6 ± 1.67 Kg/m^2). Due to acquired local lesions, two lower limbs from two cadavers were not included in this study leading to a sample of 10 lower limbs tested. The project received approval from the anatomy department subcommittee's ethic board from the XXX.

Specimen preparation

Cadavers were positioned lying supine on an experimental frame. Prior to data collection, Cadavers were thawed 48 hours. Abdomen palpation looking for soft end feel and abdominal temperature control was performed to confirm the bodies were fully thawed. All joints of the lower limbs were mobilized to ensure all joints had maximal range of motion in their anatomical planes.

The skin was incised longitudinally over eight centimeters at the antero-lateral aspect of the distal third of the leg allowing to reach the SFN (Figure 1.). Care was taken to maintain the integrity of the crural fascia where the SFN exits, preserving the moving plane of the nerve. No crural fascia were incised during the dissection. The surrounding superficial adipose tissue was cleaned using a 23-blade scalpel to obtain adequate nerve visualization.

Segmental SFN linear elongation was measured using a differential variable reluctance transducer (DVRT) with six mm stroke length (Parker LORD MircroStrain Sensing System, Williston VT). DVRT was inserted in the nerve via two barbed pegs 2 cm inferior to the exit of the SFN. The non-moving part of the sensor was sutured around the nerve's axis (figure 2) by an anatomist with over 15 years of cadaveric research experience to the nerve to ensure DVRT stability.

The communicating wire and wireless transmitter were secured to the proximo-lateral aspect of the leg using zinc-oxide tape to make sure they did not interfere with any soft tissue of the lower leg. Node Commander software (Parker LORD MircroStrain Sensing system, Williston VT) was used for data collection. The cadaver's pelvis and thorax were then secured to the experimental frame using a ratchet tie-down strap to stabilize the specimen throughout the mobilizations.

Experimental set-up and data collection

To ensure reliability and accuracy of hip movements during testing, an opto-electronic motion capture system (Prime^{X22}, Optitrack, NaturalPoint Inc., Corvallis, OR) was used. Two intracortical pins, mounted on top by one cluster of four reflective markers were introduced in the diaphysis of the femur and in the superior aspect of the anterior superior iliac spine.

Mobilization was executed by a physical therapy technologist licensed in Québec, Canada. The motion sequence constantly followed the specific order described in the reference literature:[33] 1. Maximal available ankle plantar flexion, 2. Maximal available ankle inversion, 3. Hip flexion (part of the SLR mobilization) 4. 30° of hip adduction.

The hip flexion position of the mobilization was randomized for every limb using Matlab (MathWorks, Version: R2020b, Natik, Massachusetts) to make sure nerve creep was not a confounding factor. Ankle inversion was considered a motion in the frontal plane as described by Brockett et al.[35] Each mobilization was repeated 3 times and replicated at different randomized hip flexion positions (0°/30°/60°/90°) of the SLR. Every position was maintained for a duration of two seconds to ensure stable measurements were obtained. Between trials, the limbs were then brought back to the resting position and maintained during for 1 minute to limit the possible impact of creep within the nerve. The examiner was blinded to strain data during the NDM. During all the procedures, nerve and surrounding tissues were kept hydrated by physiologic saline solution (Water and NaCl at 0.9%).

Continuous electro-mechanical measures were obtained in volts, and manufacturer's conversion curve was used to calculate displacement in mm. Elongation was then used to calculate strain of the nerve tissue. Strain (ε) was expressed as the measure of deformation of the length variation from the initial length of the nerve tissue. The following equation was used:

$$\mathcal{E} = \Delta L / L_0$$

The resulting strain is expressed as a percentage of elongation (positive value) or shrinkage (negative value). We considered the anatomical reference position as the initial measure (L_0) of length with cadavers lying supine in anatomical position.

Statistical analysis

Descriptive statistics of the strain were collected at each position of the mobilization sequence. Normal distribution of data was confirmed using Shapiro-Wilk test of normality (sig = 0.330). A one-way Analysis Of Variance (ANOVA) was then conducted on the strain measured in percentage. Post hoc Tukey test was applied for multiple comparisons. Statistical tests were performed using SPSS (Version 24., IBM, Armonk, NY) and data was extracted using MATLAB (MathWorks, Version: R2020b, Natik, Massachusetts). Independent variables were the technique sequence and hip flexion range of motion, and the dependent factor was the strain measured in the nerve tissue. A test-retest intra-rater reliability analysis of strain was conducted on two different cadavers with one hour interval between mobilisations, repeated twice following a protocol of randomization. Intra-rater reliability was measured with a two-way random effect absolute agreement intraclass correlation coefficient (ICC).

3. Results

3.1 Reliability

Mean intra-class correlation coefficient (Table 1) with absolute agreement was 0.86 in this study for the measure of strain at the end of mobilization.

3.2 Strain

Final strain measured in the SFN at the end of the mobilization with all motions combined are presented in Table 2. Compared to the anatomical resting position, significant differences in strain were produced at the nerve (7.93 ± 0.51% p<0.001).

With all motions combined at the end of mobilization, we did not observe any significant difference in strain between the different SLR hip flexion positions (Table 2) (p= 0.851).

A general view of the strain behaviors throughout the entire mobilization are presented in Figure 3. Peak strain percentage was reached following the hip flexion position during every mobilization (after INV at 0° of hip flexion). PF and INV were the main motions inducing nerve elongation at 4.66 ± 0.53% and 2.54 ± 0.18% respectively.

3.3 Motion contribution to total strain

Motion contribution to total strain is defined as the percentage a specific motion contributes to a scale of 100% which represents total strain attained at the end of mobilization (Figure 3 & 4.). Figure 3 regroups the mean contribution percentage of motions of every hip flexion level. Globally, within mobilization, PF (59.34 ± 25.82%) and INV (32.80 ± 21.41%) were consistently the highest contributors to strain noted. Nevertheless, their contribution steadily decreased as hip flexion became increasingly important as a contributor (Figure 4).

Figure 4 regroups this data by motion at different hip flexion positions. No statistical difference was found within PF (p= 0.695), INV (p= 0.643) and ADD (p= 0.202). Therefore, there is no significant contribution difference within these three specific motions whether performed at 0°, 30°, 60° or 90°. As seen in Figure 4, a significant difference was demonstrated between different hip flexion positions contribution on total strain (0°/30°/60°/90°) (p= *0.003*).

We averaged contribution values from each different position (Table 3). A one-way ANOVA was conducted to compare every different motion against the other to conclude whether a statistical difference was present. The ANOVA showed a statistically significant difference between global motions (F= 84.104. p<0.001). Post hoc Tukey analysis showed PF had a significantly higher contribution to strain than INV (p<0.001), hip flexion (p< 0.001) and ADD (p< 0.001). INV also had higher contribution than hip flexion (p< 0.001) and ADD (p< 0.001). However, no statistical difference was found between hip flexion (6.96 ± 10.56%) and ADD (0,39 ± 10.42%) (p=0.381).

4. Discussion

To our knowledge, this is the first study investigating the mechanical effect of a specific neurodynamic test of the SFN composed of hip and ankle movements on fresh cadavers. The aim of our study was to investigate the ability of a specific neurodynamic test to produce strain at the superficial fibular nerve at the exit of the crural fascia. We observed that strain is indeed produced during a neurodynamic mobilization with SFN bias (7.12-8.23%). This finding is unsurprising as other authors have described the impact of SLR mobilizations on sciatic, tibial, and plantar nerves[21] and at lumbar roots L4 through S1.[22]

Although testing of the SFN mechanosensitivity using neurodynamic has been described previously,[36] no biomechanical studies have been performed regarding nerve strain. Despite the fact the specific order of mobilization produced a significant amount of strain on the SFN, we did not find a significant difference between distinct levels of hip flexion used during the SLR component on final absolute strain (Table 2.). A previous study[37] on tibial and sciatic nerves also found that the order of mobilization may not influence final strain during SLR testing on cadavers. This implies that another order may have yielded similar results. Our findings showed that hip flexion positions during SLR might not influence final strain.

Additionally, we observed that hip flexion and ADD consistently seemed to have a lesser influence on total strain while ankle movements (PF and INV) were the main relative contributors to SFN strain (59.34%-32.80% of the total strain). This is consistent with previous studies[38] where neighboring joints to the tested nerve were elicited a greater mechanical influence. Plantar flexion was consistently the highest contributor to total strain of the SFN. This finding is supported when considering the normal anatomy of the SFN as it passes on the dorsal aspect of the foot anteriorly to the transverse axis of the ankle.

The findings in our article could also demonstrate the critical implication of the ankle motions on the testing of mechanosensitivity in the superficial fibular nerve and reinforce their impact on SFN deformation. Although hip flexion position did not cause the most strain in the evaluated segment of the SFN, it is generally used in a clinical setting as a differentiation maneuver. It's increasing contribution to strain during the mobilization is a reason why it should be used clinically for pain differentiation. However, the amount of strain found to be clinically significant in the living population has yet to be examined. We therefore cannot confirm the meaningfulness of different hip flexion levels as a differentiation maneuver as the lack of statistical difference may or may not be clinically significant. As the SLR is a test usually performed with the ankle dorsiflexed, the initial motions of this specific test could be lowering the innate neural tension at the proximal sciatic nerve, explaining why hip flexion may have a lesser influence on SFN elongation.

Previous authors[39] have studied the impact of ankle inversion as a single motion with simulated talo-fibular ligament tear in a cadaveric setting on SFN strain and excursion. They measured comparable amount of strain (3.0% to 11.6%) with an *in vitro* simulated ankle sprain relative to our study (4.15% to 10.80%). Interestingly, our results do not indicate strain over 10.80% which is far lower than the 15.7% reported previously to be detrimental to neural vascularization.[32] This SFN mobilization technique could then be considered safe to execute *In Vivo*.

Our hypothesis that hip ADD would lower the amount of strain was not confirmed across all conditions as it did not significantly change the elongation of the SFN across all mobilizations. We noted a slight reduction at 60° and 90° of SLR while having no significant effect at 0° and 30°. This reduction could indicate that a more proximal phenomenon may be happening at the gluteal region where an anchor of the sciatic nerve would change its response when mobilizing over 30° of hip ADD. We hypothesize that the lumbar plexus, passing medially to the coronal axis of the hip, may be the reason why strain seems mainly unaffected at the SFN in an adducted position of the hip. Additionally, cadaveric tissue's stress response may differ to living tissue. Comparative studies in the living should be conducted to compare different stress responses using shear wave elastography.

5. Study limitations

While this study provides new insights on neurodynamic mobilizations at the lower extremity, certain limitations arose. First, this study only considered longitudinal stresses. Other biomechanical forces such as shear and compressive forces were not studied. Secondly, during testing, the tester tried to maintain movements in the perfect anatomical planes with infrared tracking but could have induced a small amount of hip internal rotation during the ADD part of the mobilization. This could have a minimal influence on the strain on the SFN. This study is a cadaveric investigation, involving a certain amount of dissection, although minimal, which could have modified the moving plane of the nerve. The cadaver's age group included in this study does not represent the typical Athletic Trainer's population. As peripheral nerve tissue ages, stiffness increases which could change strain values compared to a younger and more active population. This could also impact the variability in strain where a younger population may present more variability emphasizing the need for the clinician to apply different movement combinations. The results are obtained in a cadaveric setting; therefore, applicability could be different in a clinical population. Our results can however be a starting point for *in vivo* studies using non-invasive measurement techniques such as shear wave elastography.

6. Conclusion

This study demonstrates that a specific NDM significantly increases longitudinal strain of the SFN. Different hip flexion position during the SLR maneuver did not seem to have an impact on final longitudinal strain, although they became a more significant contributor as the range of motion increased. Clinicians should consider ankle motions crucial to produce strain in the SFN to evaluate mechanosensitivity in patients. Our results also showed that clinicians must investigate different positions at the hip to evaluate SFN mechanosensitivity as ADD showed a significant inter-subject variable effect on strain. It is interesting to note that the ''optimal'' amount of strain during mobilization for clinical results are yet to be established. Future clinical studies are recommended to investigate the effect of ankle and hip movements on the symptoms expected to be originated from the SFN.

8. Conflict of interest

The authors do not have any conflicts to declare.

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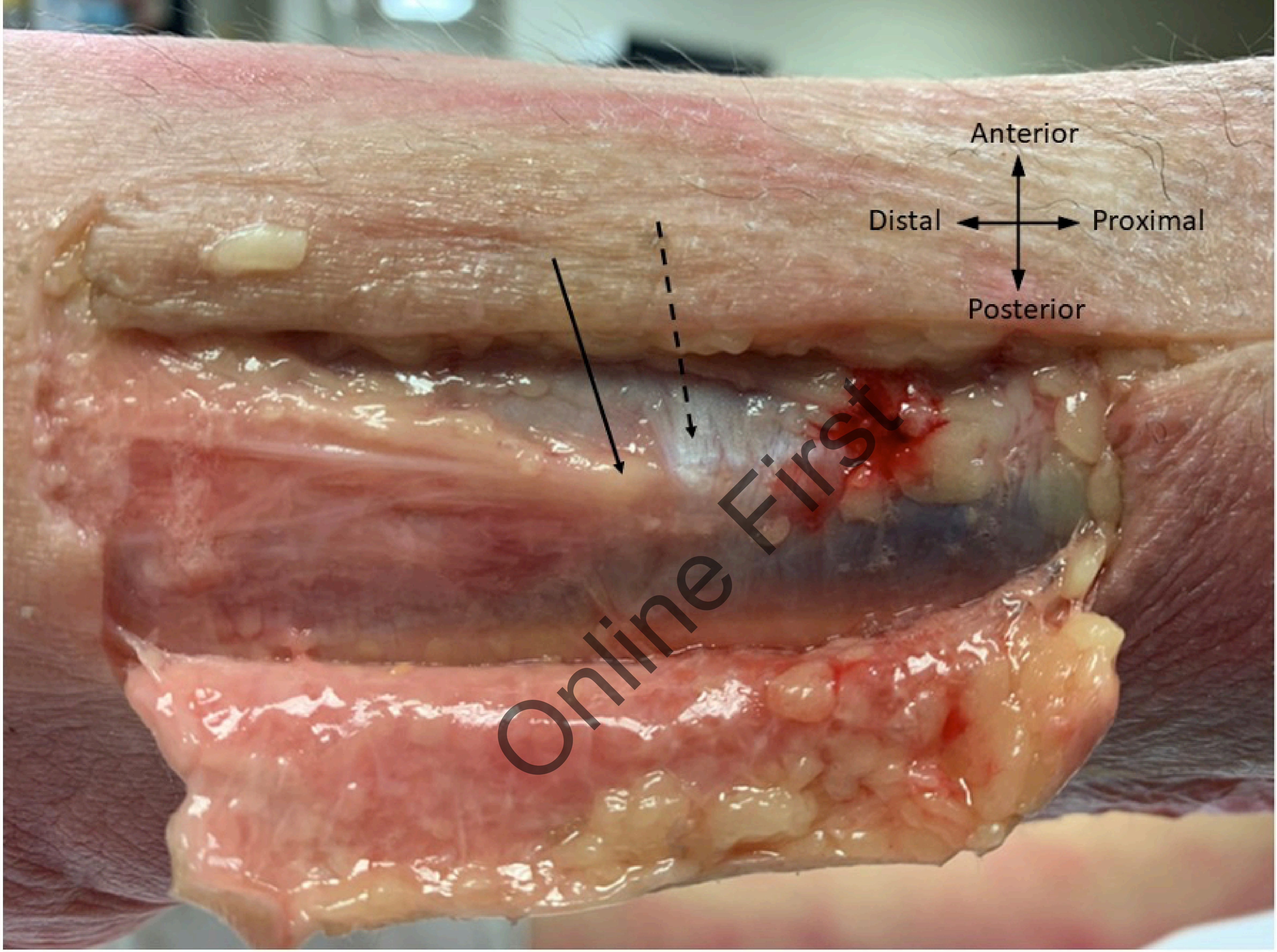

Figure 1. Dissection window of the superficial fibular nerve. Lateral view

SFN is indicated with a continuous arrow, the crural fascia is indicated with a dotted arrow

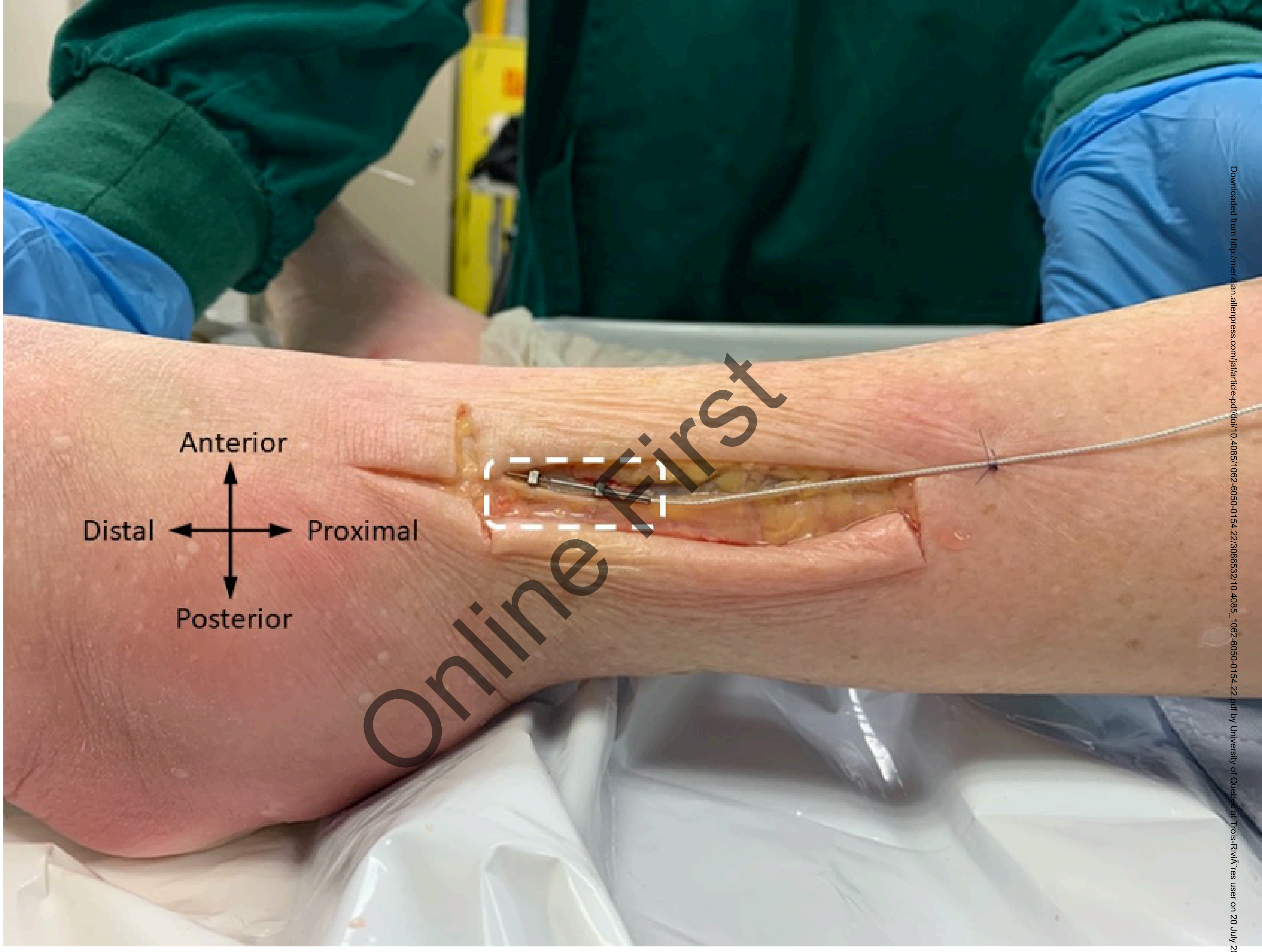

Figure 2. Electro-mechanical strain gauge (DVRT) inserted in the left SFN

The DVRT is indicated by a dotted rectangle

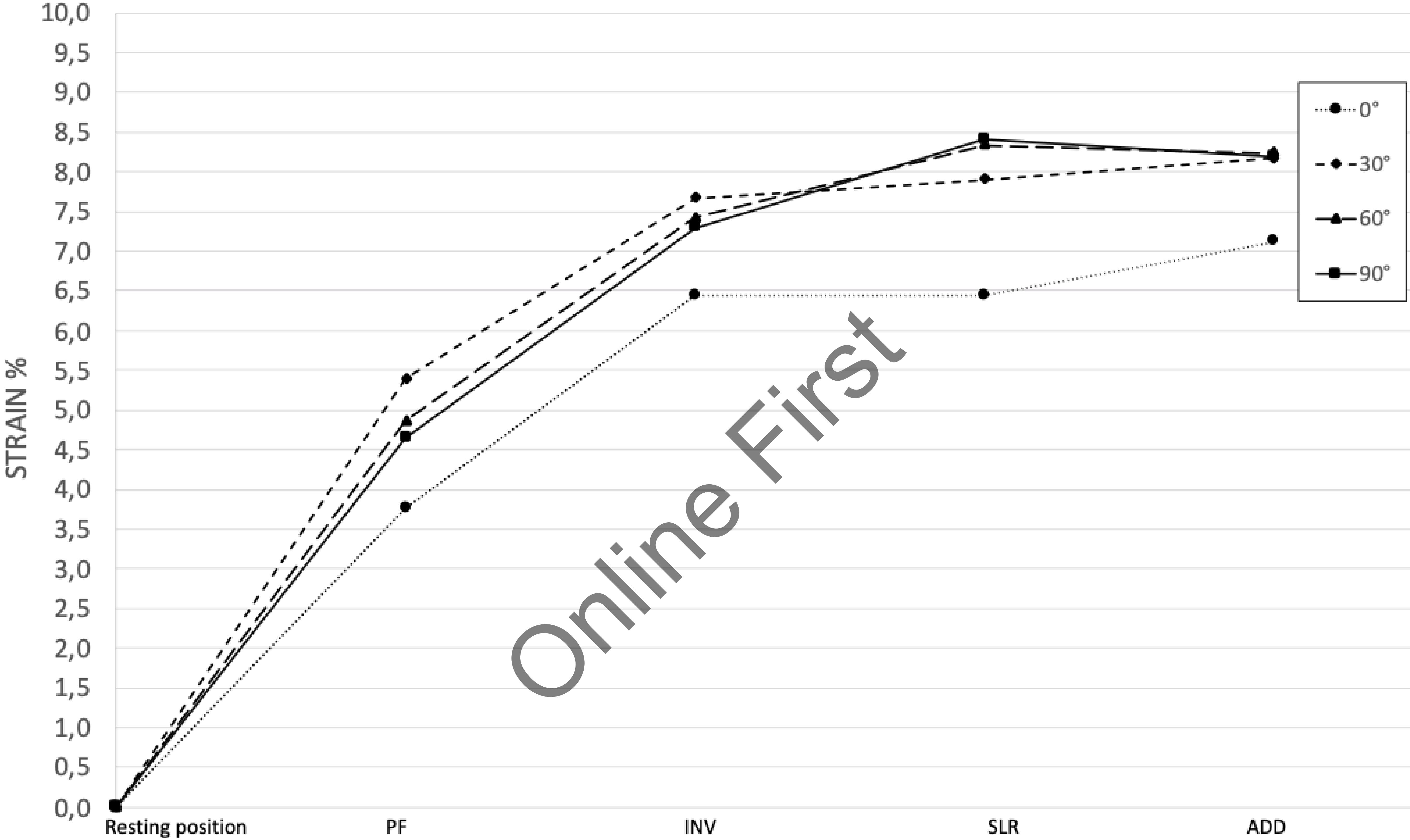

Figure 3. Strain behavior during mobilization. *X axis: motion. Y axis: strain %. PF: ankle plantar flexion, INV: ankle inversion, SLR: straight leg raise position, ADD: hip adduction*

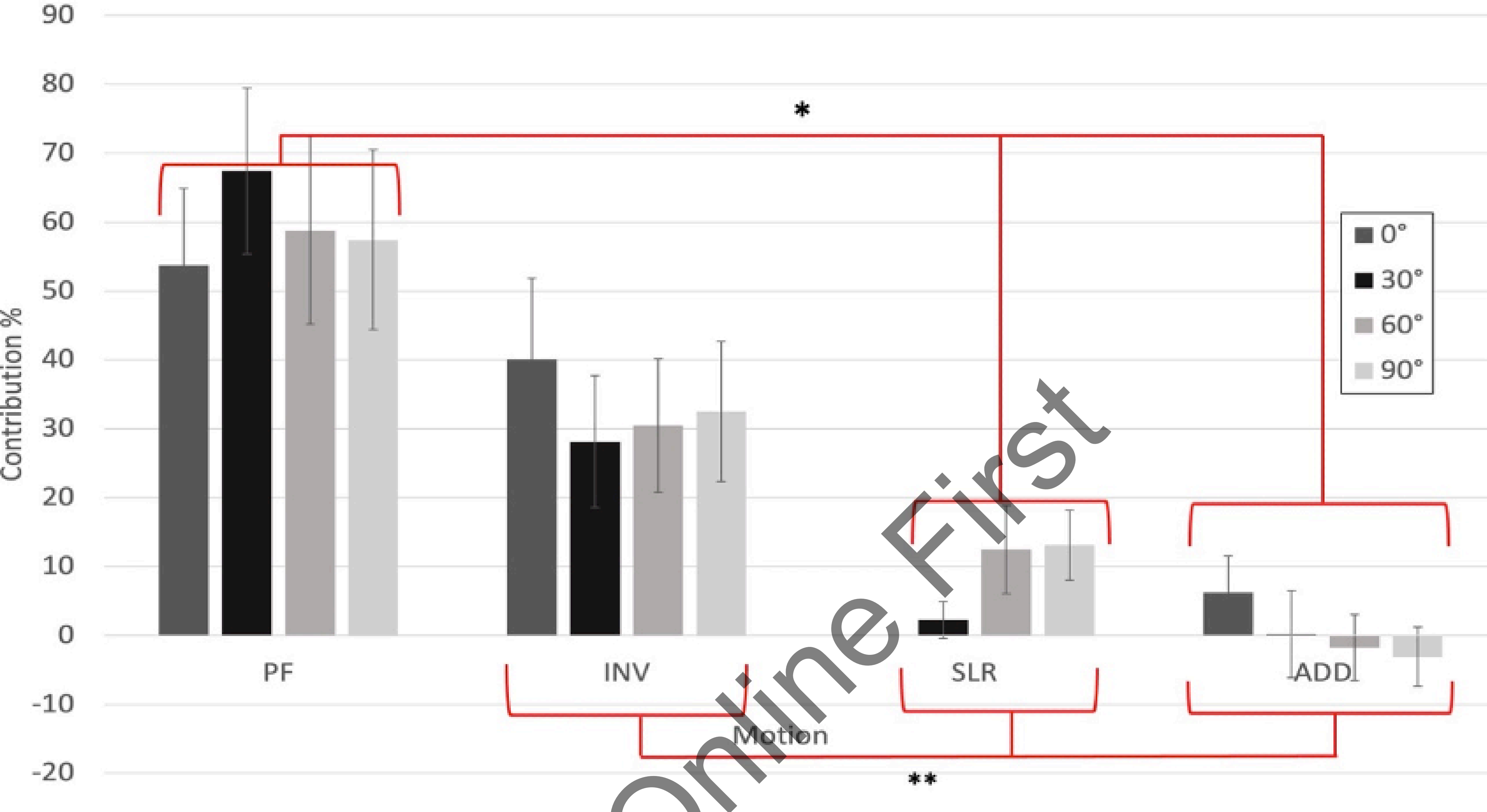

Figure 4. Relative contribution % by motion at different HF positions (0°/30°/60°/90°)

PF: ankle plantar flexion, INV: ankle inversion, SLR: straight leg raise position, ADD: hip adduction

*, **: *significant differences between groups*

Table 1. Intra-class correlation coefficient with absolute agreement and standard error of measurement (SEM)

Hip flexion (degrees)	Between sessions	Within session	SEM
0	0.80	0.95	2.07
30	0.71	0.90	0,86
60	0.98	0.79	1.14
90	0.97	0.84	0.82

Table 2. Final strain with all motions combined at different hip flexion positions.

Hip flexion position (degrees)	Final strain (strain %)	95% CI	ANOVA
°	Mean (SD)		
0	7.12 (4.14)	[4.15-10.08]	
30	8.17 (2.72)	[6.22-10.12]	
60	8.23 (3.59)	[5.66-10.80]	*p*= 0.851
90	8.19 (2.59)	[6.34-10.04]	

SD: standard deviation, CI: confidence interval, ANOVA: analysis of variance

Table 3. Global motions contribution % after grouping hip flexion positions

Motion	Relative contribution (%) (SD)	95% CI
PF	59.34 (25.82)	[51.09-67,60]
INV	32.80 (21.41)	[25.96-39.65]
HF**	6.96 (10.56)	[3.58-10.34]
ADD**	0.39 (10.42)	[-2.94-3.73]

PF: ankle plantar flexion. INV: ankle inversion. HF: hip flexion. ADD: hip adduction

** no statistical difference between these motions after Tukey's (p= 0.381)