Contents lists available at ScienceDirect

Musculoskeletal Science and Practice

Original article

Differential movement of the sciatic nerve and hamstrings during the straight leg raise with ankle dorsiflexion: Implications for diagnosis of neural aspect to hamstring disorders

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ABSTRACT

Introduction: In hamstrings injuries, sciatic nerve and muscle disorders can coexist. Therefore, differential diagnosis to include or exclude nerve involvement is an important aspect of evaluation. The objective of this paper is to investigate the mechanical behaviour of the sciatic nerve and biceps femoris muscle in the proximal thigh with the ankle dorsiflexion manoeuvre at different degrees of hip flexion during the straight leg raise in cadavers.
Material and methods: A cross-sectional study was carried out. Linear displacement transducers were inserted into the sciatic nerve and the biceps femoris muscle of 11 lower extremities from 6 fresh cadavers to measure potential strain of both structures during ankle dorsiflexion at 0°, 30°, 60° and 90° of hip flexion during the straight leg raise. Excursion was also measured with a digital calliper.
Results: Ankle dorsiflexion resulted in significant strain and distal excursion of the sciatic nerve at all ranges of hip flexion during the straight leg raise ($p < 0.05$). In contrast, the ankle movement did not affect the strain in biceps femoris at any position of the hip ($p > 0.05$).
Conclusion: Ankle dorsiflexion at different degrees of hip flexion during the straight leg raise produces changes in the strain and excursion of the sciatic nerve in the upper thigh. In contrast, the biceps femoris muscle at the same location was not affected by ankle movement. These findings show differential behaviour between the nerve and muscle with ankle dorsiflexion at this location that could be used as differential diagnosis in posterior hip pain.

1. Introduction

Hamstring injuries are an important sporting and clinical problem and are prevalent across a number of sporting codes, including football (soccer) and athletics (Van Dyk et al., 2017; Edouard et al., 2016; Eirale, 2018). Research into hamstring injuries continues to develop and has, in recent years, led to a better understanding of the problem. Even with such progress, there remains a continuing need for new knowledge of management of injuries into the posterior thigh (Brukner, 2015), particularly in relation to the potential for factors that may also involve the sciatic nerve because of its close anatomical relations with the hamstrings. The proximal end of biceps femoris at its musculo-tendinous junction and near its attachment to the ischial tuberosity is the immediate interface to the sciatic nerve. Disorders that involve this area are common and include mechanical irritation and fibrosis between the upper end of biceps and the sciatic nerve (Young et al., 2008) and rupture of the muscle (De Smet and Best, 2000), sometimes to the point of producing electrophysiological impairment of the nerve (Kouzaki et al., 2017). Whilst, in the proximal thigh, clinical problems can also occur in the other hamstrings, a finding is that biceps femoris injury is more common and the other hamstrings often occupy a secondary category in the presence of biceps injury (De Smet and Best, 2000).

Posterior hip and thigh pain, which may occur with or without sciatic nerve involvement (McCrory and Bell, 1999; Martin et al., 2016, 2018; Jackson, 2016; Haus et al., 2016; Miller et al., 2007), is one of the

most common manifestations of injuries at the proximal hamstrings (Martin et al., 2016, 2018; Haus et al., 2016). Sciatic nerve entrapment as it courses under the gluteus maximus has been defined as deep gluteal syndrome (McCrory and Bell, 1999). Deep Gluteal Syndrome (DGS) can be caused by compression of the nerve from the piriformis, gluteus, or hamstring muscles, fibrous bands surrounding the sciatic nerve (McCrory and Bell, 1999; Pérez-Bellmunt et al., 2015) and posttraumatic scarring in the deep gluteal space (Benson and Schutzer, 1999). DGS is an overlooked cause of chronic buttock and lower extremity pain and requires a specific diagnosis (Jackson, 2016).

The straight leg raise test (SLR) is the most performed physical test to examine for mechanosensitivity and impairment of mechanical function of the sciatic nerve or lumbar nerve roots in individuals with low back or lower extremity pain (Hall et al., 1998; Sierra-Silvestre et al., 2017; Capra et al., 2011; Boyd and Villa, 2012; Boyd et al., 2009; Herrington et al., 2008). It is also commonly used to evaluate the flexibility of hamstrings (Feland, 2004; Baltaci et al., 2003; Maniar et al., 2016). When sciatic nerve entrapment occurs, endoscopic decompression of the nerve can be performed (Jackson, 2016; Martin et al., 2016). When posterior hip pain results from muscle injury without evidence of nerve involvement, rehabilitation programmes aimed at muscle strengthening and stretching are the often instigated (Silder et al., 2013; Sherry and Best, 2004; Askling et al., 2013, 2014). Although, it has been described that nerve and muscle disorders can coexist (Puranen and Orava, 1988), differential diagnosis to include or exclude nerve involvement is an important aspect of patient evaluation since the therapeutic options for each would be different.

In order to differentiate responses from neural and hamstring mechanism during the SLR test, dorsiflexion of the ankle has been thought to constitute a manoeuvre that produces differential mechanical effects (movement and strain) between hamstrings and sciatic nerve (Boyd and Villa, 2012; Boyd et al., 2009; Gadjosik et al., 1985; Boland and Adams, 2000; Coppieters et al., 2006a). Studies in animals have demonstrated increased strain in the sciatic nerve at the proximal thigh when ankle dorsiflexion is added to the SLR (Babbage et al., 2007; Boyd et al., 2005). In one cadaver study, it was shown that ankle dorsiflexion produces distal movement in the tibial nerve at the knee (Coppieters et al., 2006a). However, to date and that we know of, there is no evidence in the literature of the effect of ankle dorsiflexion on the sciatic nerve in the proximal thigh in humans, nor whether the nerves moves differently from the hamstrings with such a manoeuvre. The specificity of this manoeuvre in the neural tissue at the hamstrings is at present unstudied and requires data. Results of such studies could affect clinical interpretations of the SLR with dorsiflexion in excluding or including the diagnosis of sciatic nerve involvement in disorders affecting the hamstrings.

The purpose of this study was therefore to investigate the mechanical behaviour of the sciatic nerve and biceps femoris muscle in the proximal thigh with the ankle dorsiflexion manoeuvre at different degrees of hip flexion of the SLR in cadavers. Using both, strain (elongation) and excursion (displacement) measurements of muscle and nerve, we investigated the specificity of the dorsiflexion manoeuvre for the sciatic nerve and hamstrings at different ranges of hip flexion during the SLR test.

2. Methods

2.1. Study design

A cross-sectional study was designed to document the longitudinal excursion and strain in the sciatic nerve and the biceps femoris in the proximal thigh during the ankle dorsiflexion at different angles of hip flexion during the SLR test in human cadavers. Donations were made to the institutional university anatomy laboratory of the International University of Catalonia and the institutional ethics committee approved the present study (CBAS-2018-07-1). Before the actual experiment was
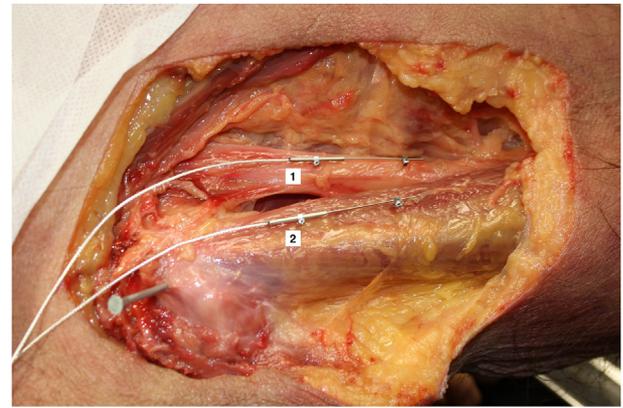

Fig. 1. Dissected right lower limb at proximal hamstrings showing the position of the strain gauges (Van Dyk et al., 2017): sciatic nerve (Edouard et al., 2016), biceps femoris muscle. Orientation: left side of the picture: proximal; right side: distal; top: lateral; and bottom: medial.

commenced, all the procedures were tested in a pilot trial in 5 additional lower extremities and reliability of strain and excursion measurements was calculated.

2.2. Cadaver specimens

The study material included 6 fresh frozen cadavers, 4 male and 2 female. The age range at time of death was 66–78 years (mean 72.83 ± 4.53). The cadavers were stored at 3 °C and brought to room temperature before testing. None of the cadaveric specimens used for this study had evidence of traumatic injuries or surgical scars. Lower extremities were excluded from the study if they had less than 90° hip flexion, less than full knee extension or less than 40° of ankle movement. Because of restriction in the range of motion of the ankle, one lower extremity was excluded from the study. Thus, the final sample included 6 fresh frozen cadavers and 11 lower extremities.

To expose the sciatic nerve and proximal end of the biceps femoris muscle, a skin flap (size 10 × 8 cm) was created immediately distal to the ischial tuberosity. Subcutaneous tissues were kept intact as much as possible in order not to compromise normal nerve and muscle mechanics (Fig. 1). Data collection commenced immediately after the dissection was made to prevent drying of the tissues.

2.3. Experimental procedures

Each cadaver was placed in contralateral side-lying. Side-lying was chosen to prevent the potentially varying gravitational effect on the strain gauge components during hip flexion (Coppieters et al., 2015). Strain and excursion measurements were made at 0°, 30°, 60° and 90° of hip flexion. Sequences of these 4 positions were performed in random order for each specimen and extremity. A universal goniometer was used to measure hip flexion angle according to standard goniometry guidelines (Norkin et al., 1995). The knee was placed in full extension and the ankle in full plantar flexion. Hip and knee positions were maintained manually and hip angles were verified goniometrically at each stage of the test. Since adduction/abduction of the hip influences tension in the sciatic nerve (Martin et al., 2017) and the response to the SLR in asymptomatic individuals (Sutton, 1979), this movement was controlled by the placement of a block between the cadavers' medial knee and the table. The ankle was then moved from maximal plantar flexion to maximal dorsiflexion. The end range of each position was determined by strong resistance perceived by the examiner who performed the movement. Whilst the magnitude of this resistance was not measured, ranges of motion of ankle movement with each sample were. The examiners who moved and measured the ankle were positioned

facing the specimen such that they were blinded to the effects of the manoeuvre on the nerve and muscle. They were also blinded to the output from the strain gauges and excursion readings.

Ankle movement was performed five times at each hip flexion position and the last three repetitions were used to calculate strain and measure excursion. Measurements were recorded by one investigator who was blinded to the SLR performance and ankle position.

2.3.1. Strain measurements

Strain in the sciatic nerve and biceps femoris were measured with 2 differential variable reluctance transducers (DVRT; Microstrain, Burlington, VT, USA) with a stroke length of 6 mm and a resolution of 1.5 μm. Strain gauges were inserted into the nerve and muscle with two barbed pins (Fig. 1), at a distance between 4 and 6 cm distal to the ischial tuberosity. The DVRT for the nerve was inserted in the medial (tibial) component of the sciatic nerve, once the limb was placed in the experimental range of SLR. This was ensure that the DVRT remained within its calibrated range. Calibration equations provided by the manufacturer were used to convert voltage output into length measurements. Because the absolute strain values might be influenced by the positioning of the reluctance transducers, changes in the relative strain were the recorded. The percentage change in strain was calculated using the formula [(end length - start length)/start length] x 100.

2.3.2. Excursion measurements

A fixed metal screw reference marker was inserted rigidly into the ischial tuberosity. The distance from this marker and the distal barb of the DVRT within the nerve and the muscle was used to measure the longitudinal excursion of the sciatic nerve and biceps femoris. A digital calliper (Vernier Digital, GOCHANGE IP54 150mm/6in) was used to measure the excursion.

2.4. Statistical analysis

The intra-class correlation coefficient (ICC) at a 95% confidence interval (CI), the standard error of measurement (SEM) and the minimum detectable difference (MDD) were calculated for the strain and excursion of the sciatic nerve and the biceps femoris muscle in the aforementioned pilot study. Interpretation of ICCs followed Portney and Watkins (1993) and included 0.00 to 0.25 = little to no relationship, 0.26 to 0.50 = fair degree of relationship, 0.51 to 0.75 = moderate to good relationship, and 0.76 to 1.00 = good to excellent relationship.

Mean and standard deviation of the strain and excursion of the sciatic nerve and biceps femoris were calculated at 0°, 30°, 60° and 90° of hip flexion. The percentage of cases with changes in strain or excursion greater than the MDD obtained in the pilot study, was also calculated.

Normal distribution of the sample was analyzed using the Shapiro-Wilk test ($p > 0.05$). Differences in the strain and excursion at 0°, 30°, 60° and 90° of hip flexion between the sciatic nerve and the biceps femoris were calculated using T student test or Mann-Whitney U test for normally or non-normally distributed data respectively. A p value < 0.05 was considered significant. All analyses were performed using SPSS Statistics Version 22.0.

3. Results

Reliability coefficients for the strain and excursion measurements of the sciatic nerve in the pilot study were excellent. Standard errors of measurement and minimum detectable differences at 95% confidence interval were small (Table 1). Because the variation in strain and excursion of the femoris muscle was zero before and after the ankle movements, the ICC was not calculated for the muscle measurements.

The ankle was moved 48.54 ± 9.29°, from 39.27 ± 9.20° plantar flexion to 9.27 ± 8.35° dorsiflexion.

Table 1

Reliability of strain and excursion measurements for the sciatic nerve.

Measurement	Hip flexion degrees	ICC	SEM	MDD
Strain (%)	0°	0.99	0.10	0.26
	30°	0.96	0.29	0.77
	60°	0.96	0.20	0.55
	90°	0.99	0.13	0.36
Excursion (mm)	0°	0.93	0.11	0.29
	30°	0.94	0.16	0.45
	60°	0.92	0.16	0.45
	90°	0.94	0.11	0.30

ICC: Intra-class correlation coefficient; SEM: Standard error of measurement; MDD: Minimum detectable difference.

Table 2

Strain and excursion measurements for the sciatic nerve and biceps femoris at the proximal hamstrings during ankle dorsiflexion at different degrees of hip flexion.

Hip flexion angle		0°	30°	60°	90°
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Strain (%)	Nerve	1.26 (1.60)	2.25 (1.94)	3.66 (2.40)	3.06 (1.94)
	Muscle	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	P values	0.002	< 0.001	< 0.001	< 0.001
Excursion (mm)	Nerve	2.13 (1.16)	2.19 (0.96)	2.11 (0.83)	1.68 (0.53)
	Muscle	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	P values	< 0.001	< 0.001	< 0.001	< 0.001

SD: Standard deviation.

3.1. Strain measurements

Strain in the sciatic nerve at the proximal hamstrings increased with the ankle dorsiflexion at all hip flexion angles (Table 2). The greatest increase in strain was shown at 60° of hip flexion (mean 3.66 ± 2.40%). However, the ankle movement did not affect the strain in biceps femoris at any position of the hip.

3.2. Excursion measurements

The data for all cases showed an excursion value of the sciatic nerve higher than MDD at all the hip flexion positions. No changes in biceps femoris excursion were shown in any of the studied positions.

The sciatic nerve at the proximal hamstrings consistently moved distally with ankle dorsiflexion in all hip flexion positions. The greatest excursion of the sciatic nerve was shown at 30° of hip flexion (mean 2.19 ± 0.96 mm) (Table 2). For biceps femoris, a similar behaviour as for the strain was observed and the muscle was not affected by the ankle movement. The pattern of change in strain and excursion of the sciatic nerve and biceps femoris at different degrees of hip flexion with ankle dorsiflexion is presented in Fig. 2.

4. Discussion

The primary aim of this study was to quantify the mechanical behaviour of the sciatic nerve and biceps femoris muscle at the proximal hamstrings at different ranges of the SLR with respect to the effect of ankle dorsiflexion. In relation to strain in the nerve, this increased with dorsiflexion, whereas biceps femoris was not affected by this movement. In relation to distal excursion of the sciatic nerve, this occurred with ankle dorsiflexion while the muscle again remained motionless. Since the nerve moved when the muscle appeared devoid of mechanical responses, these data support the dorsiflexion component of the SLR in differential diagnosis of a sciatic aspect to posterior thigh pain and proximal hamstring disorders. More specifically, if a patient's posterior upper thigh pain does not change with the dorsiflexion aspect of the
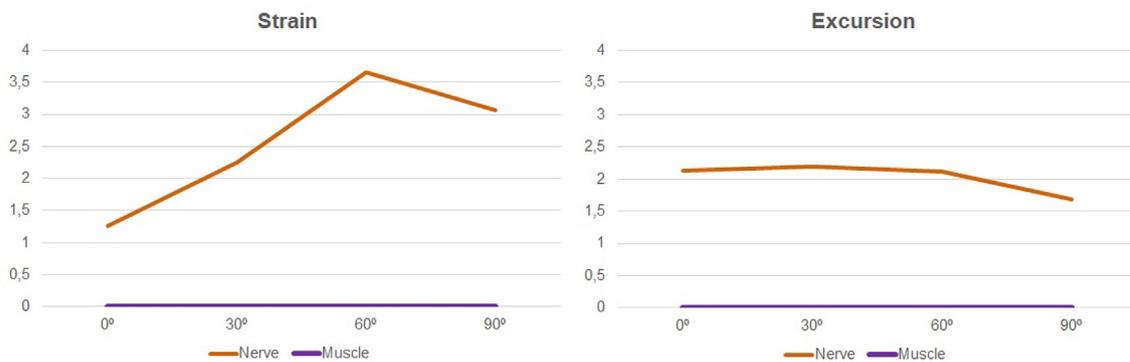
Fig. 2. Pattern of change in strain and excursion measurements of the sciatic nerve and the biceps femoris at the proximal hamstrings in the SLR with ankle dorsiflexion at different hip flexion angles.

SLR, this may be a clinical feature that helps eliminate a sciatic aspect. Conversely, if a patient's clinical pain increases with dorsiflexion, this may warrant more investigation for a neural aspect. This is particularly strong because all data sets showed sciatic nerve movement with dorsiflexion.

In the present study, the amount of excursion of the sciatic nerve during ankle dorsiflexion ranged from 1.68 to 2.19 mm. Even though excursion did not difer a greatly between 0°, 30° and 60° SLR, it was still maximium at 30°. This may have been because this angle was sufficient to impart forces between the ankle and thigh, but the capacity of the nerve to dissipate tension was not fully absorbed compared to higher ranges of SLR.

In all cases, the direction of the sliding was distal, to the joint where tension in the nerve was applied. This pattern of movement is consistent with previous studies on nerve biomechanics (Wright et al., 2001; Coppieters and Alshami, 2007; Ridehalgh et al., 2012a; Coppieters et al., 2009; Boyd et al., 2013; Alshami et al., 2008; Ko et al., 2006; Szikszay et al., 2017) and it has been defined as the "convergence mechanism" (Shacklock, 1995, 2005). According to this convergence, nerves obey Newtonian physics by sliding longitudinally toward the joint where tension is applied. The strain increase for the sciatic nerve ranged 1.26–3.66% among hip positions. The highest change in strain was observed at 60° of hip flexion. This may be clinically significant because it is the ROM where symptoms often appear during the SLR in sprinters with injured hamstrings (Askling et al., 2006), and also in asymptomatic non-sport subjects (Sierra-Silvestre et al., 2017; Boyd and Villa, 2012; Boyd et al., 2009; Herrington et al., 2008; Boland and Adams, 2000; Majlesi et al., 2008).

It is noteable that ankle dorsiflexion produced a change in the strain and/or the excursion of the sciatic nerve in the 100% of the cases, at all angles of hip flexion. However, the ankle movement did not produce changes in these parameters in the biceps femoris muscle. The fact that the changes in the nerve were higher than the MDD, indicated that they were not due to the measurement error. Also, because the nerve measurements were reliable, it can be suggested that there were no aberrations in how the repetitions were performed.

The SLR is the most applied physical test in evaluation of the sciatic nerve involvement in clinical practice (Sierra-Silvestre et al., 2017; Capra et al., 2011; Boyd and Villa, 2012; Boyd et al., 2009; Herrington et al., 2008; Ridehalgh et al., 2005, 2012b; Cleland et al., 2006; Shacklock et al., 2016). As in other tests designed to assess the mechanosensitivity and mechanical function of the neural system, the structural differentiation manoeuvre has been proposed as necessary to make a differential diagnosis between muscle or nerve involvement (Herrington et al., 2008; Shacklock, 1995; Bueno-Gracia et al., 2016; Nee et al., 2012; Butler, 2000). The rationale for the structural differentiation is based on the supposed specificity of the manoeuvre to produce changes in the strain or excursion in the nerve but not in the

muscle at the final test position. The findings of the present study have shown that ankle dorsiflexion resulted in a specific movement for the sciatic nerve at the proximal hamstrings, reflected by the increased strain or excursion at different degrees of hip flexion. These results support ankle dorsiflexion in differentiation between nerve and biceps femoris involvement in patients with upper hamstring disorders and posterior thigh pain. In both the upper and lower limb, it has been also shown that experimentally-induced muscle pain did not change when such differentiating manoeuvres were performed (Coppieters et al., 2005, 2006b) and the present study in consistent with those findings. This finding lends support to the idea that such differentiation manoeuvres may extend to perception and the validity of these manoeuvres during neurodynamic testing is supported by the present study.

The present study has certain limitations. This investigation was localised to the effect of the dorsiflexion test in the context of the SLR so as to gain information on its capacity to produce differential effects between and muscle and nerve. The tension, excursion and torsion of both the sciatic nerve and biceps femoris muscle were not measured throughout entire the SLR. Other factors require investigation in order to place this study in its rightful context which is only an aspect of the SLR in diagnosis. Since we did not study the dynamics of the SLR per se, the results must be interpreted accordingly.

5. Conclusion

The present study showed that ankle dorsiflexion at different degrees of hip flexion during the SLR produced changes in the strain and excursion of the sciatic nerve at the proximal hamstrings. In contrast, the biceps femoris muscle at the same location was not affected by ankle movement. These findings show differential behaviour between the nerve and muscle with ankle dorsiflexion at this location which supports this movement as a differential diagnosis manoeuvre in patients with upper hamstring disorders and posterior hip and thigh pain.

Ethics committee approval of the study protocol

The local Ethical Committee approved the present study - reference number CBAS-2018-07-1.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.msksp.2019.07.011.

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