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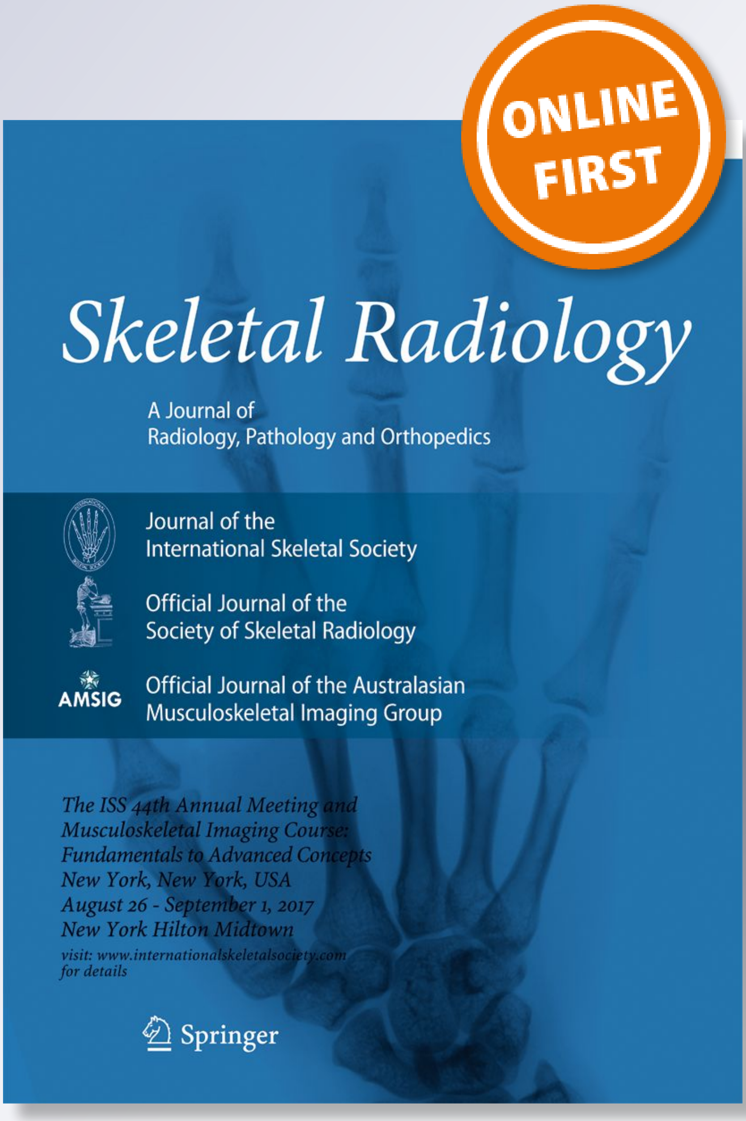

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SCIENTIFIC ARTICLE

Gemelli-obturator complex in the deep gluteal space: an anatomic and dynamic study

Ramon Balius[1,2] · Antonio Susín[3] · Carles Morros[4] · Montse Pujol[1,5] · Dolores Pérez-Cuenca[4] · Xavier Sala-Blanch[6,7]

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Abstract

Objective To investigate the behavior of the sciatic nerve during hip rotation at subgluteal space.

Materials and methods Sonographic examination (high-resolution ultrasound machine at 5.0–14 MHZ) of the gemelli-obturator internus complex following two approaches: (1) a study on cadavers and (2) a study on healthy volunteers. The cadavers were examined in pronation, pelvis-fixed position by forcing internal and external rotations of the hip with the knee in 90° flexion. Healthy volunteers were examined during passive internal and external hip rotation (prone position; lumbar and pelvic regions fixed). Subjects with a history of major trauma, surgery or pathologies affecting the examined regions were excluded.

Results The analysis included eight hemipelvis from six fresh cadavers and 31 healthy volunteers. The anatomical study revealed the presence of connective tissue attaching the sciatic nerve to the structures of the gemellus-obturator system at deep subgluteal space. The amplitude of the nerve curvature during rotating position was significantly greater than during resting position. During passive internal rotation, the sciatic nerve of both cadavers and healthy volunteers transformed from a straight structure to a curved structure tethered at two points as the tendon of the obturator internus contracted downwards. Conversely, external hip rotation caused the nerve to relax.

Conclusion Anatomically, the sciatic nerve is closely related to the gemelli-obturator internus complex. This relationship results in a reproducible dynamic behavior of the sciatic nerve during passive hip rotation, which may contribute to explain the pathological mechanisms of the obturator internal gemellus syndrome.

Keywords Deep gluteal syndrome · Gemelli-obturator internus complex · Sciatic nerve · Obturator internal gemellus syndrome

Introduction

The sciatic nerve arises from the lumbosacral plexus, from roots L4– S2. This nerve typically runs from its origin, at the greater sciatic foramen, to the popliteal fossa, where it divides into two branches. Along this route, two areas with clearly defined pathways can be distinguished: one in the deep gluteal space, and the other at the level of the thigh. In the gluteal space, the sciatic nerve is protected from the sacrum by the pyramidal muscle, and later from the ischium by the gemellus muscles (superior and inferior), the obturator internus, and, finally, the quadratus femoris muscle. This deep pathway to the gluteus maximus is mainly characterized by the nerve's curved layout until reaching the second part of the route, at the level of the thigh [1, 2]. Upon reaching the thigh, the sciatic nerve takes on a rectilinear route, deep into the long section of the biceps femoris.

Due to anatomical variations, repeated microtraumas, or just the passing of years (aging), characteristic clinical cases

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occur due to nervous dysfunction, like, for example, secondary pseudo-sciatica, or dysfunction caused by entrapment of the sciatic nerve at the level of the piriformis muscle, known as pyramidal syndrome [3–5]. Recently, it has been observed that the sciatic dysfunction in the pelvis was not only caused by different types of conflict with the pyramidal muscle, but there were also conflicts at other levels, giving rise to the concept of deep gluteal syndrome [1, 2, 6]. One of these causes is sometimes attributed to the gemelli-obturator internus complex [7–9].

On the other hand, there is an increasing interest in neurodynamics as a therapeutic instrument and to preserve health. Currently, there are neurodynamic assessments guiding rehabilitators to perform preventive treatments focused on the major nerves [10]. Thus, different studies have assessed how articular movements affect the normal biomechanics of the sciatic nerve in the thigh [11–17] or the pelvis [18]. However, these studies were exclusively focused on flexion-extension movements of the coccyx-femoral joint.

Given the anatomical layout of the sciatic nerve in the gemelli-obturator internus complex, and based on neurodynamics previous studies showing "gliding" of this nerve during the flexion-extension of the hip, we attempted to assess the sciatic nerve's behavior at this level with hip rotation maneuvers. The hypothesis was that the gemelli-obturator internus complex is closely related to the sciatic nerve, thus providing a specific, reproducible and constant behavior for these neuromuscular structures during internal and external rotations of the hip.

Materials and methods

Anatomical and US studies in cadavers

The study included fresh cadavers of both adult men and women, with no surgical history of lumbar spine, pelvis or hip, and without history of inflammatory medical pathologies (osteoarthritis). The study on cadavers was approved by the Ethics and Research Committee of the School of Medicine at the University of Barcelona, and carried out in the Human Anatomy lab of the School of Medicine at the University of Barcelona. The cadavers were kept at a temperature of 4 °C for 36 h, until reaching the usual screening results for the safety of the cadaver handlers. The cadavers were placed in prone position, with a 10-cm cushion located in the pelvic area, causing a 10–15° flexion of the coccyx-femoral joint, with the pelvis fixed in a support. The cadavers were kept in the dissection lab, at a room temperature of 22–23 °C, for a minimum period of 4 h before the beginning of the study.

An ultrasound of the sciatic nerve's behavior was performed during passive mobilization maneuvers of the limb.

Ultrasound scanning was performed with an Aplio 500 (TUS-500 5.0 Platinum Series, manufactured by Toshiba Medical Systems Corporation in Nasu, Japan) using a high-frequency linear array probe (PLT 1005BT), 5.0–14 MHz frequency range. Most commonly used 2D frequency was differential harmonic of 14 MHz (diffTHI 14 MHz). The depth used was 5 cm, with a single focus at 1.8 cm and a dynamic range of 65 dB. A sonographic examination of the long-axis sciatic nerve was performed. Internal and external rotations of the hip were performed with the knee at 90° flexion, while the sciatic nerve was observed by ultrasound in order to evaluate its behavior. The scans were performed by one of the authors (R.B.), with over 23 years of experience in musculo-skeletal sonography. Ultrasound images obtained were saved in image and video formats.

After obtaining the images, the corresponding anatomical dissection was performed (Fig. 1). A dissection in planes of the specimens was performed by two experienced anatomists (CM and XSB). The skin and superficial fascia of the gluteal area were removed first, followed by sectioning of the gluteus maximus lateral third, about 3–4 cm of its femoral insertion. By removing the superficial planes, the sciatic nerve was freed from its posterior and internal relations and attachments basically through the inferior gluteal nerve and vessels, and from the posterior skin nerve of the thigh. Superior relationships (with the superior gluteal nerve and vessels) as well as mean-caudal relationships (with the nerve and pudendal vessels) were kept intact. Internal and external rotation maneuvers of the hip were subsequently performed, similarly to those carried out with ultrasound. Nerve movements were assessed in relation to its muscle/tendon support in the gemelli-obturator internus complex. Anatomical images

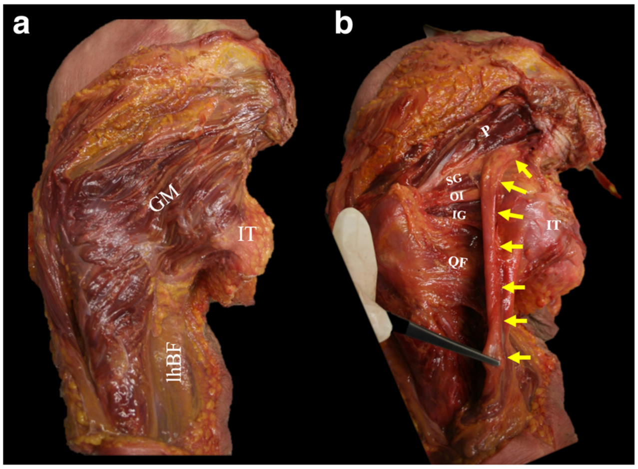

Fig. 1 Anatomical dissection of the gluteal area. **a** Superficial gluteal area. **b** Deep gluteal space. GM gluteus maximus muscle, IT ischial tuberosity, lhBF long head of biceps femoris. P piriformis muscle, SG superior gemellus muscle, OI obturator internus muscle, IG inferior gemellus muscle, QF quadratus femoris muscle. Arrow pathway of the sciatic nerve

obtained were photographed, and the sciatic nerve movement was filmed in direct view.

Healthy volunteer study

Participants

The study was approved by the Clinical Research Ethics Committee of the Catalan Sports administration, and informed consent was obtained from all participants. A high-resolution ultrasound was used to assess sciatic behavior in the subgluteal space of a group of young athletes. To be eligible, participants must be healthy, over 18 years old, and must not have pelvic and/or hip pathologies or symptoms indicative of sciatic nerve dysfunction. Participants were excluded if they had a history of major trauma or surgery to the lumbar, hip, gluteal or hamstring origin regions; a positive straight leg raise test; or sciatic nerve impairment. Participants were also excluded if they had any pathology that might alter the function of the nervous system.

Imaging

There is absolute consensus about the use of US for the dynamic assessment of nerves [10, 14]; moreover, in order to study healthy population, the use of a nonionizing radiation system is an ethical advantage.

Movement of the sciatic nerve was assessed in deep gluteal area, distal to inferior edge of piriformis muscle and proximal to superior edge of quadratus femoris muscle. The changes in the shape of the sciatic nerve at the beginning and end of different neural mobilization exercises have been quantified in terms of the curvature of the nerve in longitudinal captures. Initial short-axis imaging of the posterior buttock allowed localization of the sciatic nerve. Once identified, the probe was rotated approximately 90° in order to find the sciatic nerve in long axis. A sonographer with 23 years of experience (RB) performed all ultrasound scans. A high-resolution ultrasound machine was used (TUS-A500 “Aplio 500” 5.0 Platinum, manufactured by Toshiba Medical Systems Corporation in Nasu, Japan), with a high-frequency linear array probe (PLT-1005BT linear array, range of frequency 5.0–14 MHz). Preset characteristics were a depth of 5 cm, with single focus at 1.8 cm and dynamic range of 69%. A video of the nerve movement was recorded for each exercise trial. The video sequence had a capture rate of 30 frames per second.

Hip mobilization exercises and its evaluation

The volunteer was placed on a stretcher in prone position and the pelvis strapped to the bed, leaving the buttocks free in order to fix the lumbar and pelvis regions during mobilization of the hips.

Each participant performed two different motions, namely, a passive external hip rotation and a passive internal hip rotation. While these actions were carried out, sciatic behavior and range of motion (ROM) were evaluated by long-axis ultrasound. Each maneuver was recorded three times, choosing the one best visualized by ultrasound.

Ultrasound image analysis

In each recorded video, two representative frames (beginning and end of the exercise) where manually selected, and the sciatic nerve was manually segmented on the images by a senior analyst (Fig. 2a, Fig. 2b). This way, for the longitudinal captures, the nerve appears as a band in the ultrasound images (Fig. 2c, Fig. 2d). We used MATLAB (The MathWorks Inc., Natick, MA, USA) software to first compute the medial axis of this band as the representative curve of the nerve, and then we computed its curvature. Curvature κ of a point $P = [x(t), y(t)]$ belonging to a curve is mathematically defined as the inverse of the radius of the tangent circumference to the curve in this point [19]. It can be computed from the coordinate derivatives using the formula:

$$\kappa = \frac{x' y'' - x'' y'}{\sqrt{\left(x'^2 + y'^2\right)^3}}$$

The curvature of a curve is a good descriptor of the local shape of a curve, and it allows us to compare the shape of the sciatic nerve at the beginning and at the end of the motion. A curvature value $\kappa = 0$ is associated to a flat curve (a straight line) and non-zero values correspond to proper curves. Moreover, positive and negative curvature values correspond to convex or concave parts of the curve, respectively.

Due to possible misalignments during motion recording, an anchor point, corresponding to a selected point of the posterior part of the acetabulum, has been used in order to align the sciatic nerve in the two images.

Results

Anatomical and US studies in cadavers

A dissection of eight hemipelvis from six fresh cadavers (four men and two women, aged 64–82) was performed. The sonologist noted that, in all cadaveric specimens, visualization of the sciatic nerve was enough in order to control its behavior during internal and external rotations. In all cases, there was evidence of muscle tension during internal rotation. The tendon of the obturator internus muscle showed a most striking, constant depression, which was identified on all 8 samples assessed. This fact caused the sciatic nerve to curve, especially

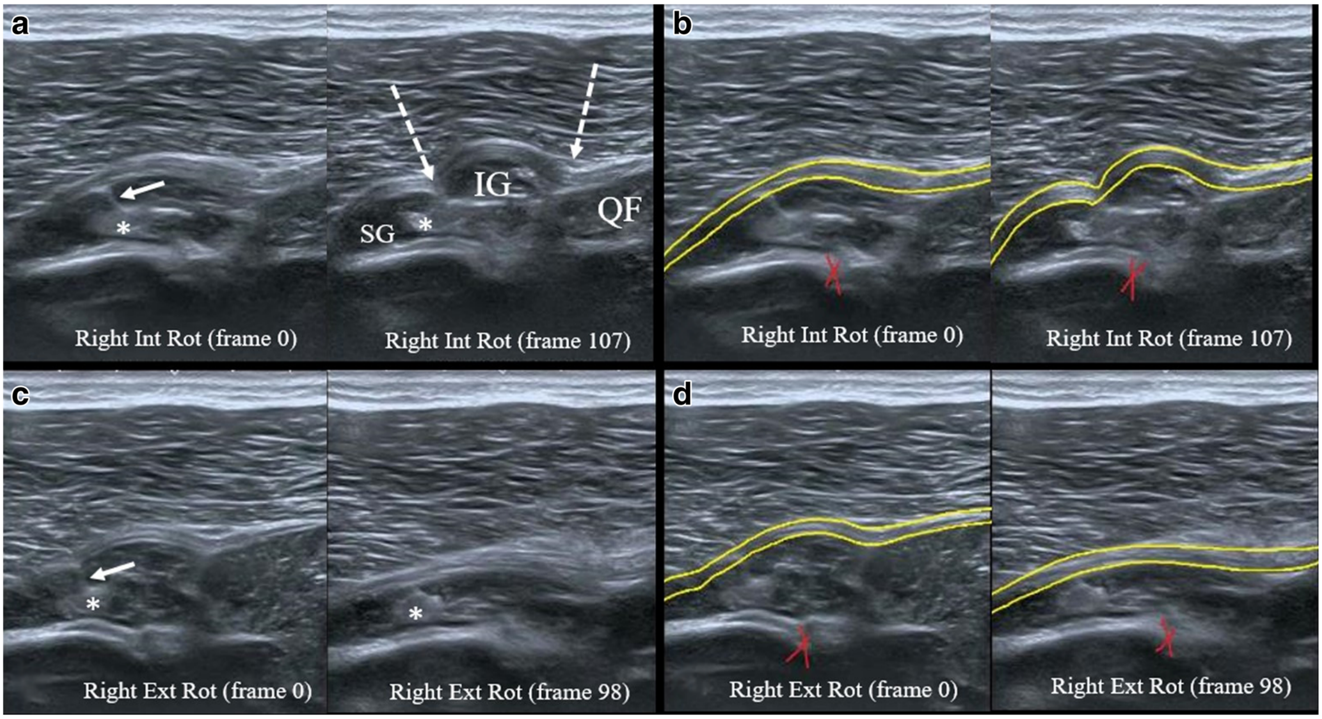

Fig. 2 US study of the sciatic nerve's behavior during internal rotation (**a** and **c**) and external rotation (**b** and **d**). Each image includes the initial frame (left) and last frame (right). The sciatic nerve is shown in yellow and the anchor point in red (**c** and **d**). Also the sciatic nerve is shown as an echoic and fibrillar tubular structure (**a** and **b**). During internal rotation (**a** and **c**), the sciatic nerve is tractioned at the level of the obturator internus (left dotted arrow) and of the inferior gemellus with the quadratus femoris muscle (right dotted arrow). SG superior gemellus muscle, (*) obturator internus muscle, IG inferior gemellus muscle, QF quadratus femoris muscle. Notice visualization of the connective anchorage of the tendon of the obturator internus with the sciatic nerve, especially during internal rotation of the hip (continuous arrow)

when intersecting the tendon of the obturator internus—Fig. 3a and Video 1 of the electronic supplementary material (ESM). Furthermore, it was also observed that the sciatic nerve suffered another (less significant) angulation at the distal border of the inferior gemellus (between this and the quadratus femoris muscle). On the other hand, the nerve corrected itself through external rotation movements, with objectification of its loss of tension (Fig. 3b and Video 1 of the ESM).

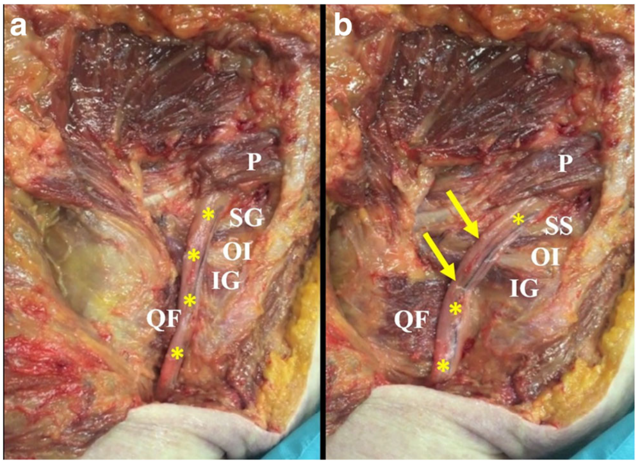

Fig. 3 Dynamic study of the sciatic nerve with external rotation of the hip (**a**) and internal rotation of the hip (**b**). Notice how the sciatic nerve (*) corrects itself during external rotation, and curves at two levels during internal rotation (arrows). P piriformis muscle, SG superior gemellus muscle, OI obturator internus muscle, IG inferior gemellus muscle, QF quadratus femoris muscle

The elevation of the nerve indicated the presence of connective tissue joining the nerve with deep tissues. In particular, the constant presence of a connective anchorage at the level of the sciatic nerve with the tendon of the obturator internus was objectified. This anchorage, although constant, varied as an entity, having a very close relationship in some samples, but not so much in others (Fig. 4 and Video 2 of the ESM). No other remarkable connective support was observed at the level of the two gemellus muscles.

Healthy volunteer study

A total of 39 volunteers were evaluated. Of these, 8 individuals were excluded due to difficulty to correctly visualize the deep gluteal space with an ultrasound, so the sample was reduced to 31 cases (14 men and 17 women) with a mean age of 21.1 ± 2.7 years, a height of 173.5 ± 3.8 cm, a weight of 65.7 ± 6.6 kg and a BMI of 20.9 ± 3.5.

Instead of studying, for instance, the elongation of the sciatic nerve, we focused on the description of the shape of the nerve with rotation of the hip. The longitudinal motion of the

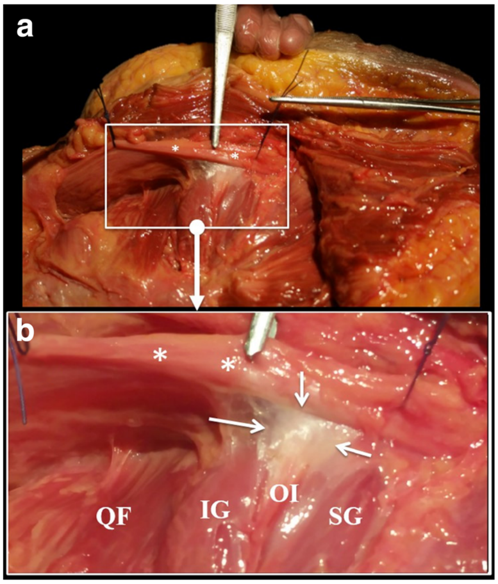

Fig. 4 Anatomical study of the relationship between the sciatic nerve and the obturator internus. The sciatic nerve (*) is separated by two threads that traction it, enabling us to see the connective anchorage of this nerve with the tendon of the obturator internus (arrows). SG superior gemellus muscle, OI obturator internus muscle, IG inferior gemellus muscle, QF quadratus femoris muscle

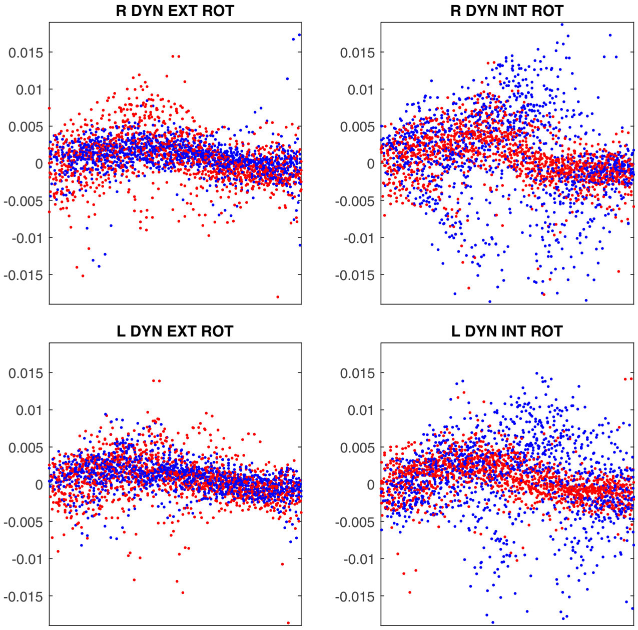

Fig. 5 Curvature values for the sciatic nerve: red dots are associated to the starting position of the nerve, and blue dots to the final position after the motion. In each column, R (right) and L (left) leg rotation motions are shown. More amplitude in the curvature values is found on the right column corresponding to dynamic internal rotation

sciatic nerve was recorded in order to understand how the global shape of the nerve is conditioned by the anatomical structures involved in the motion.

It was observed how, during the passive movement of internal rotation, the sciatic nerve assumed a typical curvature, caused by angulation of the nerve when intersecting the tendon of the obturator internus. Occasionally, a small and less steep angulation was also observed at the distal border of the inferior gemellus (Fig. 2a and Video 3 of the ESM. During passive maneuvers of external rotation, the sciatic nerve was observed to correct its layout above the gemelli-obturator complex (Fig. 2b and Video 3 of the ESM).

It was decided to quantify the deformation of the curve from the initial rest shape to the final rotated shape of the nerve. When comparing the initial and final curvature values for these two curves, significant differences are observed (Fig. 5) in terms of amplitude and mean values for each curve. In Fig. 5, all curvature values were plotted for both curves and all participants. Red points are associated to initial shapes and blue points to final shapes. On the right column, red points can be seen concentrated near zero values (quite flat), while blue points reach higher values, meaning that final curves are different and less flat than at the beginning.

Statistical boxplot of the results are presented in Fig. 6, where the curvature for the initial shape for all 31 participants are compared to the final shape obtained after each motion. The units for the obtained numerical values are expressed in terms of image coordinates (not in metric system) because the study was mainly interested in pointing out the differences between the shapes of two curves (initial and final). From the computed Wilcoxon *p*-value a significance difference ($p < 0.05$) was obtained in all the motions except for the isometric internal rotation motion.

Discussion

Our anatomical article shows the presence of connective tissue attaching the sciatic nerve to muscle/tendon structures of the gemellus-obturator system at a deep gluteal level. The sciatic nerve has attachment systems that keep anatomical relationships stable in the buttocks [20]. These support mechanisms are formed by collateral branches of the sciatic nerve (the most well-known are superior gluteal nerve, inferior gluteal nerve, posterior skin nerve of the thigh) [1]; but also by the nerves and vessels of the pyramidal, gemellus, obturator internus and quadratus femoris muscles (superior and inferior gluteal arteries with terminal ischial branch). These attachment systems are associated with the paraneural connective tissue, which acts as a “gliding system” with adjacent tissues or muscles (with its corresponding perimysium). Thus, the skeletal-muscular system acts as a neural container, and forms a mechanical interface for the nervous system [10]. The connective joint between the tendon of the obturator internus and the sciatic nerve described in this article probably has a fundamental role in maintaining the pelvic curved pathway of the nerve and is the last significant anchorage from which the

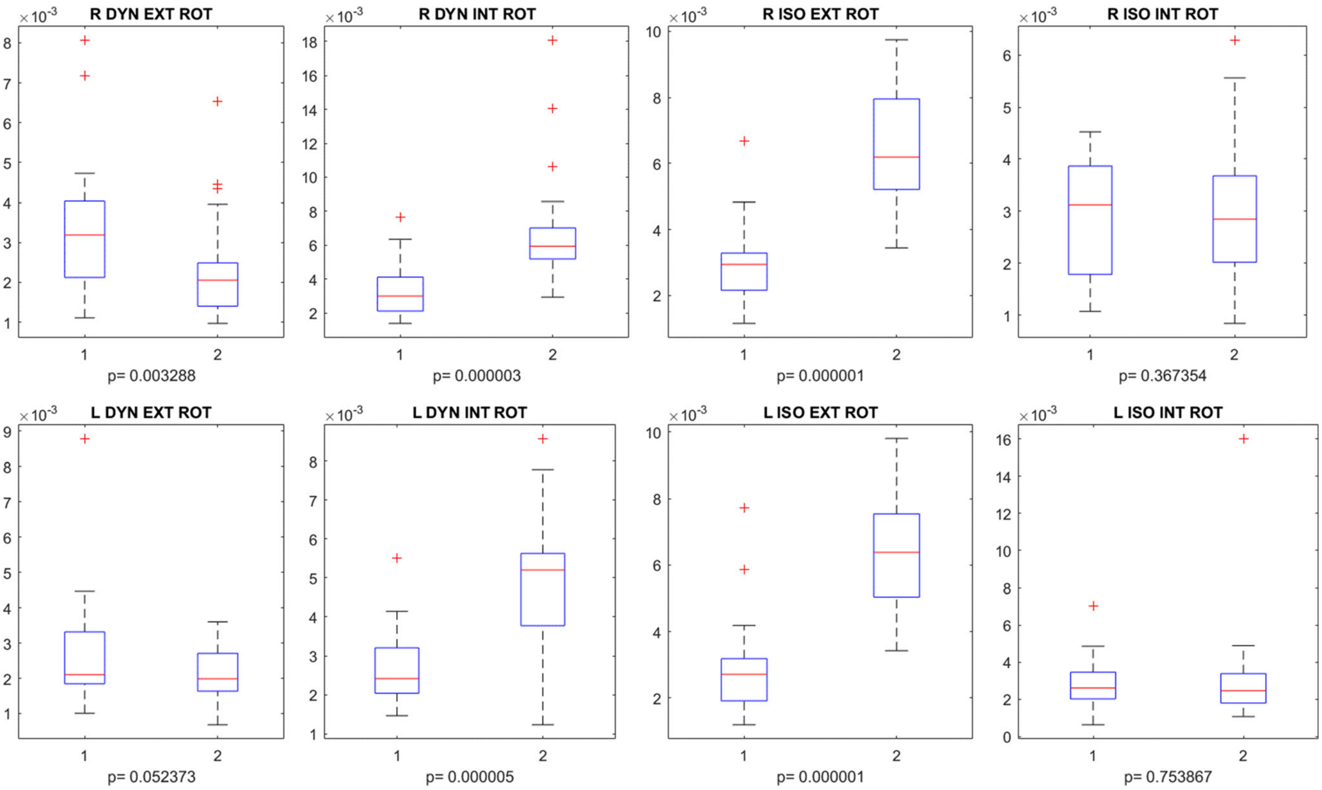

Fig. 6 Statistical boxplot representation of the curvature values for the sciatic nerve for all the participants. For each type of motion, curvature of the starting (left boxplot) and final shape of the nerve (rigth boxplot) is shown. Each boxplot represent the distribution of the data in quartiles and shows the median value (red line). The *p*-values of the Wilcoxon paired rank test for equality of medians between starting and final shape are reported

nerve assumes a straighter route. Thus, this connective anchorage acts as a real stabilizer of the neural pathway, preventing any lateral movements. In the cadavers study, the connective anchorage was constant but with varied significance. Sometimes, the nerve was observed to be strongly joined to the tendon and, other times, this joint, although still present, was less important. This fact could explain why Filler and Gilmer-Hill [21] observed that sometimes the sciatic nerve did not touch the tendon of the obturator internus, but other times it was entrapped by it.

To assess the subgluteal space with precision, a high-end ultrasound machine was used that is able to easily visualize deep anatomical areas in a group of athletic, young and thin individuals (BMI of 21.4 ± 2.4 kg/m^2). This way, the sciatic nerve's behavior during passive mobilization of internal and external rotations of the hip could be easily objectified. Several times, it was even possible to objectify the connective joint between the tendon of the obturator internus and the sciatic nerve (Fig. 4 and Video 3 of the ESM).

Neurodynamic characteristics of the sciatic nerve have been studied by several authors, virtually always at the level of the thigh—Ellis et al. [13] assessed the extension of the knee combined with cervical flexion-extension and Coppieters et al. [15] assessed mixed movements of flexion-extension of the hip and/or knee. Sciatic behavior has also been studied during the Straight Leg Raise Test [16, 17, 22]. As already mentioned, all studies have focused on different levels of articular flexion-extension movements, but the sciatic nerve's behavior during rotation movements of the hip has never been assessed. Hall et al. [23] observed that cervical flexion associated with raising a straight leg did not show any significant movement of the sciatic nerve with hip flexion. These authors have concluded that cervical flexion did not have a significant effect on neural tissue's compliance during increase of straight leg. This fact was later confirmed by Ellis et al. [13] when failing to observe any differences in the sciatic nerve excursion during mobilization of the knee alone (2.6 ± 1.4 mm) or mobilization of the knee with cervical flexion (2.6 ± 1.5 mm); furthermore, isolated tension applied at cervical level caused minimal excursion of the sciatic nerve (−0.1 ± 0.1 mm). The anchorage observed in the obturator internus can contribute to override the proximal transmission of neural tension from the cervical rachis to the thigh.

During passive maneuvers of internal rotation of the hip, the tendon of the obturator internus is contracted downwards (anterior position). The sciatic nerve anchored to this structure follows it, tracing a characteristic curvature that can be observed both in healthy volunteers and in the cadavers study (Fig. 7a). During passive maneuvers of external rotation, the tendon of the obturator internus loses tension, allowing the

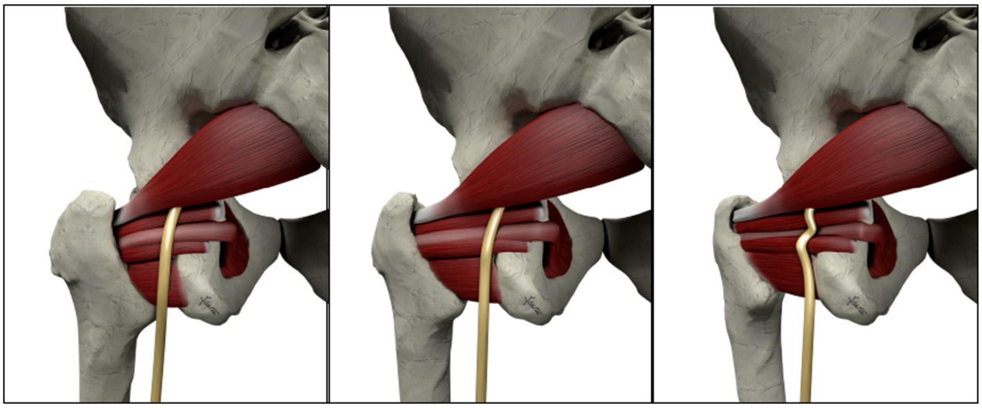

Fig. 7 Illustrative diagram of the sciatic nerve's behavior during hip rotations. During external rotation, the tendon of the obturator internus lacks tension, and the sciatic nerve relaxes, assuming a straighter appearance. During internal rotation, the tendon of the obturator internus and gemelli tightens, followed by the sciatic nerve, which suffers a curvature. P Piriformis muscle, SG superior gemellus muscle, OI obturator internus muscle, IG inferior gemellus muscle, QF quadratus femoris muscle, (*) Sciatic nerve

sciatic nerve to relax and assume a straighter appearance (Fig. 7b).

This characteristic and reproducible dynamic behavior of the sciatic nerve could be involved in pathological processes; thus, it could be related with the obturator internus/gemellus syndrome [1, 2, 7, 24]. Clinical doctors must include this syndrome in the differential diagnosis of non-discogenic sciatica. As in the case of the pyramidal syndrome, the diagnosis of the obturator internus/gemellus syndrome is usually performed by ruling out other possible causes of sciatic pain [2, 24]. Murata [7] recommends to orient this diagnosis using the PACE or Freiberg tests at a fast pace. Repeated and fast anterior traction and curvature of the sciatic nerve, caused by the tendon of the obturator internus, justifies a continuous shearing of the sciatic nerve produced by these tests.

Due to the proximity and similarity between the structure and function of the pyramidal muscle and the obturator internus, many diagnoses and treatments for the pyramidal syndrome also affect the obturator internus/gemellus syndrome, with which it is confused [21]. In one anatomical study, the tendon of the piriformis muscle was found to blend with the tendon of the obturator internus in 48 of 112 cases [9]. This indicates a strong interaction between the piriformis muscle, the obturator internus and the sciatic nerve, and a possible entrapment point. On the other hand, the sciatic nerve runs under the belly of the piriformis muscle and over the gemelli superior-obturator internus complex, causing a scissor effect between the two muscles that can be a source of entrapment [1, 2, 24]. This scissor effect can increase during internal rotation of the hip, if it is considered that the sciatic nerve's connective anchorage to the obturator internus tractions it further downward (anterior position). Sometimes, this traction is part of a few neurological tests for the diagnosis of deep gluteal syndrome, involving passive internal rotation, like the Freiberg and FAIR tests [2].

On the other hand, obturator internus muscle spasms cause sciatica, often due to irritation or entrapment of the nerve of the obturator internus [9, 25]. This nerve exits through the greater sciatic hole, between the sciatic and the pudendal nerves, branches out into retrosciatic space, and reaches the lesser sciatic opening, innervating the obturator internus muscle [21]. If the connective anchorage of the sciatic nerve to the tendon of the obturator internus is considered, this muscle's constant contraction could prevent the sciatic nerve from moving naturally and cause pain at this level.

This study shows several limitations. The sciatic nerve was freed from its posterior anatomical attachments (gluteus maximus, as well as vessels and inferior gluteal nerve, and posterior skin nerve of the thigh), which might modify the shape assumed by the nerve during rotations of the hip. Lack of muscle tone in the anatomical sample would also affect this deformity and, finally, rotations of the hip were restricted by the advanced age of the cadavers. However, these limitations probably tend to underestimate, instead of overestimate, the movement. Regarding the sample of healthy volunteers, they were all young muscular individuals, so the shape assumed by the nerve could overestimate the effect with respect to that observed in general population. In this sense, new studies focused on older populations with different physical conditions are necessary to confirm the neurodynamic behavior described in this study and estimate the significance of the effect.

In conclusion, our study provides evidence about the anatomical relationship between the sciatic nerve and the gemelli-obturator internus complex, as well as about the dynamic behavior of the characteristic and reproducible sciatic nerve during passive rotation maneuvers of the hip. In the future, these findings might have an interesting role in the differential diagnosis of deep gluteal syndrome. However, it is necessary to perform broad population studies to prove the presence of this dynamic behavior in other population groups, both healthy and with pathologies.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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