



ORIGINAL ARTICLE

Sciatic Nerve-Piriformis Muscle Variations and Their Association with Fibrovascular Tethering: A Cadaveric Study with Implications for Deep Gluteal Syndrome

Dian Mediana¹, Magdalena Wartono¹, Purnamawati Tjhin¹, Nabila Maudy Salma^{1*}, Tjam Diana Samara¹

¹Department of Anatomy, Faculty of Medicine, Trisakti University, Indonesia

Correspondence: Nabila Maudy Salma (nmsalma@trisakti.ac.id)

Received: 16 December 2021 | **Revised:** 08 April 2022 | **Accepted:** 03 May 2022 | **Published:** 02 July 2022

Keywords: sciatic nerve | piriformis muscle | deep gluteal syndrome | anatomic variation | cadaveric dissection | nerve entrapment | endoscopic decompression

ABSTRACT

We dissected 60 formalin-fixed adult cadavers, giving 120 gluteal regions, in order to measure the piriformis muscle and the sciatic nerve, record how often anatomical variants occur, and test whether variant anatomy is associated with fibrovascular tethering in the deep gluteal space. Standard gluteal dissection exposed the greater sciatic foramen, and every side was classified using the Beaton and Anson criteria. Mean piriformis length was 84.5 ± 7.2 mm, and it was greater in males (86.8 ± 6.9 mm) than in females (81.3 ± 6.5 mm, $p = 0.041$). The sciatic nerve measured 15.8 ± 2.4 mm in width at its exit from the foramen and 4.9 ± 0.8 mm in thickness; neither differed between the sexes. The nerve lay 29.4 ± 3.8 mm from the greater trochanter on the right and 28.9 ± 4.1 mm on the left ($p = 0.652$), and 27.2 ± 3.5 mm and 27.8 ± 3.2 mm from the ischial tuberosity ($p = 0.418$). Type 1 anatomy was present on 81.7% of sides, while variants (Types 2–5) accounted for 18.3%. Fibrovascular tethering was found on 14.3% of Type 1 sides but on 68.2% of variant sides, giving a relative risk of 4.7 ($p < 0.001$). Variant sciatic nerve-piriformis relationships therefore carry a much higher risk of fascial entrapment. We suggest that fascial release should be planned more extensively during endoscopic gluteal decompression when a variant is present, particularly in refractory deep gluteal syndrome.

ABBREVIATIONS

CFN	common fibular nerve	PM	piriformis muscle
DGS	deep gluteal syndrome	SD	standard deviation
mm	millimetre	SN	sciatic nerve
n	number of specimens	SPSS	Statistical Package for the Social Sciences
p	probability value	TN	tibial nerve

ARTICLE INFORMATION

How to cite this article: Mediana, D., Wartono, M., Tjhin, P., Salma, N. M., & Samara, T. D. (2022). Sciatic nerve-piriformis muscle variations and their association with fibrovascular tethering: A cadaveric study with implications for deep gluteal syndrome. *Indo Eurasian Journal of Medical Sciences*, 1(1), 1–8.

Ethics: The study protocol was approved by the Institutional Ethics Committee of the Faculty of Medicine, Trisakti University, Indonesia (Approval Number: ANAT/2021/00-54; Date: 15 August 2021). All cadavers came from the institutional body donation programme.

Study design: Cross-sectional cadaveric study; 60 formalin-fixed adult cadavers (120 gluteal regions) dissected bilaterally, with sciatic nerve-piriformis relationships classified by the Beaton and Anson criteria.

SUMMARY

1. **Variant anatomy is common.** Across 120 gluteal regions from 60 formalin-fixed cadavers, 81.7% showed Beaton and Anson Type 1 anatomy and 18.3% (22 specimens) showed Types 2 to 5; Type 6 was not seen.
2. **Tethering tracks with variation.** Fibrovascular tethering was present in 68.2% of variant specimens (15 of 22) against 14.3% of normal specimens (14 of 98), a relative risk of 4.7.
3. **The piriformis is sexually dimorphic, the nerve is not.** Muscle length was 84.5 ± 7.2 mm overall and longer in males (86.8 ± 6.9 vs 81.3 ± 6.5 mm, $p = 0.041$), while sciatic nerve width (15.8 ± 2.4 mm) showed no sex difference.
4. **Landmarks are stable side to side.** The nerve lay 29.4 ± 3.8 mm from the greater trochanter on the right and 28.9 ± 4.1 mm on the left ($p = 0.652$), and slightly closer to the ischial tuberosity at 27.2 ± 3.5 and 27.8 ± 3.2 mm ($p = 0.418$).
5. **Surgical implication.** Because tethering accompanies roughly seven in ten variant specimens, aggressive fascial release should be anticipated during endoscopic gluteal decompression in refractory deep gluteal syndrome.

1 | Introduction

Deep gluteal syndrome (DGS) is a group of entrapment neuropathies caused by compression of the sciatic nerve within the subgluteal space, a region bounded above by the piriformis muscle, in front by the gemelli-obturator internus complex, and behind by the gluteus maximus [1]. Among its causes, piriformis syndrome is the one most often recognised, in which the piriformis muscle itself compresses the nerve, usually when the muscle is hypertrophied, in spasm, or anatomically variant [2]. Because patients present with gluteal pain, sciatica, and limited function, the picture closely resembles lumbar radiculopathy, and the diagnosis is often delayed [3].

The way the sciatic nerve relates to the piriformis muscle is clinically important, since variations in this relationship predispose the nerve to compression and may explain part of why some decompressions fail [4]. The relationship has interested clinicians for more than a century, and the classification published by Beaton and Anson in 1938 remains the standard framework, dividing it into six types according to the course of the nerve or its divisions relative to the muscle [5]. In Type 1 the undivided nerve passes below the muscle, which is the usual arrangement. The variant types are the common fibular nerve piercing the muscle (Type 2), the common fibular nerve passing above it (Type 3), the undivided nerve running through a bifid muscle (Type 4), and the rarer Types 5 and 6. Cadaveric series have placed the prevalence of variant anatomy between 12% and 22%, with Type 2 reported most often, and a meta-analysis of 44 studies put the overall figure at 16.9% [4]. These arrangements are common enough to be planned for rather than treated as anomalies.

The clinical weight of the variants comes from their link with entrapment. A systematic review of the clinical features of piriformis syndrome found that variant sciatic nerve-piriformis configurations were more often associated with entrapment symptoms than normal anatomy was [6]. Endoscopic series have also shown that fibrovascular bands, meaning fibrous connective tissue that ties the nerve to the structures around it, are found in a large share of patients at the time of decompression, and are met more often when the anatomy is variant [7]. Even so, no study has measured the relative risk of tethering in variant compared with normal anatomy under a standardised cadaveric dissection protocol.

Treatment has moved towards endoscopic decompression, which is minimally invasive. A review of the technique

reported good outcomes in 85% of patients, the essential steps being identification of the sciatic nerve, release of the piriformis tendon, and excision of any fibrovascular bands [2]. Success depends heavily on the surgeon knowing which variants to expect. Missing one leaves the nerve incompletely decompressed and the symptoms unchanged, which is the reason preoperative imaging and careful intraoperative inspection are recommended [3].

What is still missing is a study that examines morphometry, surgical topography, and fascial tethering together. Most earlier work has counted the variants alone, without asking whether those variants are accompanied by fibrovascular bands that tether the nerve inside the deep gluteal space [6]. Surgical landmark distances, namely how far the nerve lies from the greater trochanter and from the ischial tuberosity, are needed for endoscopic planning, yet they have seldom been reported together with variant anatomy [7].

We therefore set out to measure the piriformis muscle and the sciatic nerve, to record the frequency of the Beaton and Anson types, to establish landmark distances useful for endoscopic decompression, and to test whether variant anatomy is associated with fibrovascular tethering. Our hypothesis was that variant sciatic nerve-piriformis relationships carry a higher risk of fascial entrapment than normal anatomy does.

2 | Materials and Methods

2.1 | Study Design and Specimen Characteristics

This was a cross-sectional observational study carried out on cadavers. We examined 60 formalin-fixed adult human cadavers, which gave 120 gluteal regions for bilateral analysis. The cohort consisted of 35 male and 25 female cadavers, with a mean age at death of 71.2 ± 8.4 years. All cadavers came from the institutional body donation programme of the Faculty of Medicine, Trisakti University. The study protocol was approved by the Institutional Ethics Committee of the Faculty of Medicine, Trisakti University, Indonesia (Approval Number: ANAT/2021/00-54; Date: 15 August 2021). Cadavers with evidence of previous gluteal surgery, trauma, or gross deformity were excluded so that the native anatomical relationships remained intact.

2.2 | Dissection Technique and Morphometric Measurements

Each cadaver was placed prone for a standard gluteal dissection. A curvilinear incision was made along the posterior iliac crest, carried laterally to the greater trochanter and then medially to the sacrum, so that the gluteus maximus could be reflected as a full-thickness flap. This exposed the deep gluteal space and its contents: the piriformis muscle, the gemelli-obturator internus complex, and the sciatic nerve where it leaves the greater sciatic foramen. During this first exposure we took care not to disturb the fibrovascular bands and the fascial investments around the nerve, since these were part of what we intended to assess.

Measurements were taken with a digital caliper reading to 0.1 mm. Piriformis length was measured from the origin on the anterior surface of the sacrum to the insertion on the superior border of the greater trochanter, and piriformis

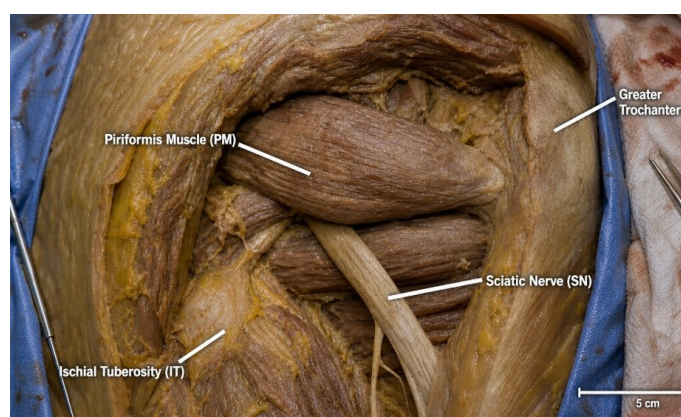


FIGURE 1A | Gross anatomical view of the gluteal region during initial dissection, exposing the deep gluteal space and demonstrating the measurement baseline for the piriformis muscle.



FIGURE 1B | Close-up view utilizing digital calipers to record precise morphometric dimensions of the sciatic nerve width and muscle thickness at the greater sciatic foramen.

2.4 | Classification of Anatomical Variations

The relationship between the sciatic nerve and the piriformis muscle was classified using the Beaton and Anson criteria, which describe six types. Type 1 is normal anatomy, with the whole nerve passing below the muscle. In Type 2 the common fibular nerve passes through the muscle while the tibial nerve passes below it. In Type 3 the common fibular nerve passes above the muscle and the tibial nerve below it. Type 4 is the undivided nerve passing through a bifid piriformis. Type 5 is the common fibular nerve above the muscle with the tibial nerve passing through it. Type 6, in which the whole nerve passes above the muscle, was also to be recorded if seen. Two investigators classified each gluteal region independently, and disagreements were settled by consensus.

2.5 | Assessment of Fibrovascular Tethering

After classification, each specimen was assessed for fibrovascular tethering. We defined tethering as distinct fibrous connective tissue bands anchoring the sciatic nerve to the surrounding muscle or fascial planes and limiting its movement within the deep gluteal space. The nerve was mobilised gently with a blunt probe, and we looked for taut bands that restricted its excursion. Tethering was recorded

width at the widest point of the muscle belly. Sciatic nerve width was measured where the nerve leaves the greater sciatic foramen, immediately distal to the piriformis, and nerve thickness in the anteroposterior plane at the same point. Right and left sides were recorded separately, and a mean was calculated for each parameter.

2.3 | Surgical Topographic Measurements

Two distances were measured to give surgical landmarks for endoscopic gluteal decompression. The first was from the lateral border of the sciatic nerve to the most prominent point of the greater trochanter, which represents the lateral surgical corridor. The second was from the medial border of the nerve to the ischial tuberosity, representing the medial corridor. Both were taken with the hip in neutral extension and the limb in neutral rotation, the position normally used for endoscopic procedures. All topographic measurements were recorded on both sides and expressed as mean $\pm$ standard deviation.

as present or absent, and the position of any band relative to the piriformis muscle was noted.

2.6 | Statistical Analysis

Data were analysed with SPSS version 26.0 (IBM Corporation). Continuous variables, that is the morphometric measurements and the topographic distances, are given as mean $\pm$ standard deviation. Independent samples t-tests were used to compare the sexes and to compare right with left sides. The chi-square test was used for the association between variation type and the presence of fibrovascular tethering. Relative risk was calculated to express how much more likely tethering was in variant than in normal anatomy. A *p* value below 0.05 was taken as significant, and 95% confidence intervals were calculated where appropriate.

3 | Results

The results are set out in four parts: the morphometric dimensions of the piriformis muscle and sciatic nerve, the topographic distances relevant to endoscopic decompression, the prevalence of the Beaton and Anson types, and finally the relationship between variant anatomy and fibrovascular tethering.

3.1 | Morphometric Dimensions

The measurements showed clear sex differences in the muscle but not in the nerve. Mean piriformis length across all 120 gluteal specimens was 84.5 ± 7.2 mm. Male specimens gave a mean of 86.8 ± 6.9 mm and female specimens 81.3 ± 6.5 mm, a difference that reached significance ($p = 0.041$). This is in line with earlier morphometric series reporting larger musculoskeletal dimensions in male cadavers, which most likely follows from general differences in body habitus and skeletal frame [8].

Piriformis width at the belly, taken at the widest point, had a mean of 31.4 ± 4.8 mm. The same pattern appeared here: 32.9 ± 4.5 mm in males against 29.3 ± 4.2 mm in females ($p = 0.028$). Earlier anatomical work has reported similar sex-based differences in the piriformis, and these

differences may matter for the biomechanics of nerve compression in the deep gluteal space [4].

The nerve behaved differently. Sciatic nerve width at its exit from the greater sciatic foramen averaged 15.8 ± 2.4 mm over all specimens, 16.1 ± 2.3 mm in males and 15.4 ± 2.5 mm in females, and the difference did not reach significance ($p = 0.315$). Nerve thickness in the anteroposterior plane at the same point averaged 4.9 ± 0.8 mm, being 5.0 ± 0.8 mm in males and 4.8 ± 0.7 mm in females, again without a significant difference ($p = 0.204$). Peripheral nerve dimensions appear to be more conserved between the sexes than musculoskeletal structures are [9].

The morphometric data are summarized in Table 1, which presents the mean values and standard deviations for each parameter along with the corresponding p -values for sex comparisons.

TABLE 1 | Morphometric dimensions of the piriformis muscle and sciatic nerve.

Parameter	Total (n=120)	Male (n=70)	Female (n=50)	p-value
Piriformis muscle length (mm)	84.5 ± 7.2	86.8 ± 6.9	81.3 ± 6.5	0.041
Piriformis muscle width at belly (mm)	31.4 ± 4.8	32.9 ± 4.5	29.3 ± 4.2	0.028
Sciatic nerve width at exit (mm)	15.8 ± 2.4	16.1 ± 2.3	15.4 ± 2.5	0.315
Sciatic nerve thickness (mm)	4.9 ± 0.8	5.0 ± 0.8	4.8 ± 0.7	0.204

That the muscle differs between the sexes while the nerve does not suggests the nerve occupies a relatively fixed space that is less affected by overall body size. If so, the ratio of nerve diameter to the surrounding muscle would differ between men and women, which could in turn affect how susceptible the nerve is to compression in the deep gluteal space. This remains a hypothesis, and biomechanical study would be needed to test it.

3.2 | Surgical Topographic Distances

To give reference points for endoscopic gluteal decompression, we measured the distance from the sciatic nerve to two bony landmarks, the greater trochanter laterally and the ischial tuberosity medially, on both sides. From the lateral border of the nerve to the greater trochanter the mean was 29.4 ± 3.8 mm on the right and 28.9 ± 4.1 mm on the left, with no significant difference

between sides ($p = 0.652$). From the medial border to the ischial tuberosity the mean was 27.2 ± 3.5 mm on the right and 27.8 ± 3.2 mm on the left, again without a significant difference ($p = 0.418$). Previous reports have likewise described bilateral symmetry in the topographic relationships of the sciatic nerve in the deep gluteal space [9].

On both sides the nerve sat slightly closer to the ischial tuberosity than to the greater trochanter, the medial distance being about 1.5 to 2.0 mm shorter. This has a practical consequence for the choice of approach. A medial portal reaches the nerve more directly, whereas the wider lateral clearance to the greater trochanter leaves more room for instruments. These topographic data are summarized in Table 2, which presents the mean distances and standard deviations for each landmark on both sides.

TABLE 2 | Surgical topographic distances from the sciatic nerve to bony landmarks.

Landmark	Right side (mm)	Left side (mm)	p-value
Lateral border of SN to greater trochanter	29.4 ± 3.8	28.9 ± 4.1	0.652
Medial border of SN to ischial tuberosity	27.2 ± 3.5	27.8 ± 3.2	0.418

Because the two sides did not differ, a standard approach can reasonably be applied bilaterally without much modification. The spread within each measurement is another matter: standard deviations of 3.2 to 4.1 mm mean that individual anatomy varies enough to justify preoperative imaging in each patient. Earlier surgical anatomy studies have made the same point about planning from cross-sectional imaging [7]. The consistent medial position of the nerve relative to the ischial tuberosity in our cohort gives a dependable reference for portal placement

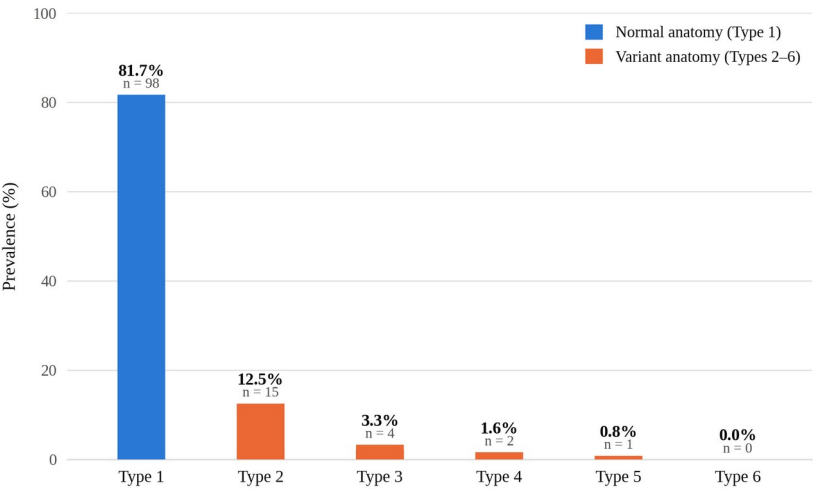
and instrument trajectory, and may help reduce iatrogenic nerve injury.

3.3 | Prevalence of Beaton and Anson Types

Classifying the 120 gluteal specimens by the Beaton and Anson criteria produced a range of configurations, set out in Table 3. Type 1 normal anatomy predominated at 81.7% ($n=98$), while the variants taken together (Types 2–5) accounted for 18.3% ($n=22$). Type 2 was the commonest single variant at 12.5% (Graph 1).

TABLE 3 | Prevalence of Beaton and Anson classification types.

Beaton and Anson Type	Description	Number of specimens (n)	Percentage (%)
Type 1	Entire SN passes below PM	98	81.7
Type 2	CFN passes through PM, TN passes below PM	15	12.5
Type 3	CFN passes above PM, TN passes below PM	4	3.3
Type 4	Entire SN passes through bifid PM	2	1.6
Type 5	CFN passes above PM, TN passes through PM	1	0.8
Type 6	Entire SN passes above PM	0	0.0



GRAPH 1 | Distribution of Sciatic Nerve and Piriformis Muscle Anatomical Variations (Beaton and Anson Classification)

Type 1, in which the undivided sciatic nerve passes below the piriformis, was the most frequent finding, seen in 98 specimens (81.7%). This is close to the pooled estimate of 83.1% from cadaveric meta-analysis [4] and confirms that the typical arrangement predominates across populations.

Type 2 was the commonest variant, found in 15 specimens (12.5%). Here the common fibular nerve pierces the piriformis while the tibial nerve passes below it. Published series have consistently identified Type 2 as the most frequent variation, with reported rates of 10% to 15% [4]. Its importance is that the common fibular nerve can be compressed inside the muscle substance, especially when the muscle contracts or hypertrophies, which may show clinically as foot drop or sensory disturbance over the lateral leg [3].

Type 3, with the common fibular nerve above the piriformis and the tibial nerve below it, was seen in 4 specimens

(3.3%). Although less frequent than Type 2, it deserves attention because the common fibular nerve runs a more superficial and exposed course above the muscle, where it can be compressed by the overlying gluteus maximus or by external pressure [5]. Our figure sits within the 2% to 5% reported previously [8].

Type 4, the undivided nerve passing through a bifid piriformis, was found in 2 specimens (1.6%). In this arrangement the muscle is split into two bellies with the nerve running between them, forming a fibromuscular tunnel that can compress the nerve dynamically during hip rotation or muscle contraction [6]. The rate in our cohort falls within the reported 0.5% to 3% [4]. Several of these arrangements are shown in Figure 2: normal anatomy with the undivided nerve emerging inferiorly (Figure 2A), the higher-risk pattern in which the common fibular nerve pierces the muscle belly (Figure 2B), and the less usual undivided nerve traversing a bifid muscle (Figure 2C).

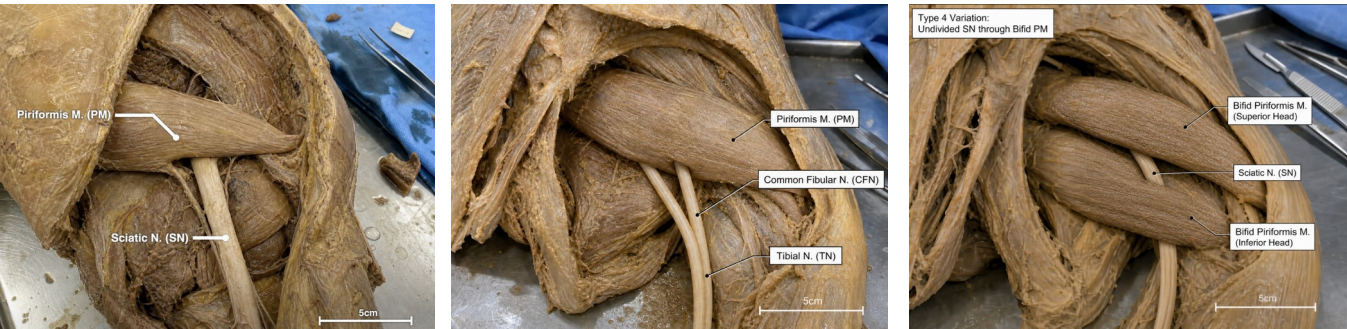


FIGURE 2A | Gross anatomical dissection of the right gluteal region showing Beaton and Anson Type 1 variation (normal anatomy), with the undivided sciatic nerve emerging inferior to the intact piriformis muscle.

FIGURE 2B | Gross anatomical dissection showing Beaton and Anson Type 2 variation, where the common fibular nerve pierces directly through the belly of the piriformis muscle while the tibial nerve passes inferiorly.

FIGURE 2C | Gross anatomical dissection showing Beaton and Anson Type 4 variation, displaying an undivided sciatic nerve passing through a distinct bifid piriformis muscle belly.

Type 5, the common fibular nerve above the piriformis with the tibial nerve passing through it, was the rarest variant we met, in a single specimen (0.8%). This configuration is documented only in isolated case reports and small series [9]. Finding it here is a reminder that the deep gluteal space should be explored thoroughly at operation, because a surgeon working from typical expectations alone may easily miss such an arrangement.

Type 6, the whole nerve passing above the piriformis, did not occur in any of our 120 specimens. This agrees with the literature, where Type 6 is described in only a handful of cases worldwide [1]. Its absence here probably reflects genuine rarity, though with a finite sample we cannot rule out sampling variation.

The overall variation rate was 18.3% (22 of 120 specimens), within the 12% to 22% reported by earlier cadaveric studies [4]. In practical terms, close to one patient in five coming to endoscopic gluteal decompression will have anatomy that departs from the Type 1 pattern. The order of frequency in our cohort, Type 2 followed by Types 3, 4, and 5, matches the pattern described in the meta-analysis by Poutoglidou et al. [4], which suggests our sample is reasonably representative.

The surgical consequences differ from one variant to another. In Type 2 the surgeon has to free the common fibular nerve from within the muscle belly, which may call for a partial myotomy of the piriformis. In Type 3 the superior course of the common fibular nerve usually requires a wider dissection above the muscle. Type 4 needs the two bellies of the bifid muscle to be identified and separated before the nerve can be decompressed. Type 5, rare as it is, demands careful dissection to find both the common fibular nerve above the muscle and the tibial nerve within it. Recognising which type is present, whether on preoperative imaging or at exploration, is therefore part of achieving a complete decompression [7].

3.4 | Clinical Correlation of Fascial Band Entrapment

To see what the anatomical variations meant in practice, we assessed fibrovascular tethering in all 120 gluteal specimens and set the findings against the Beaton and Anson type. Tethering, defined as distinct fibrous bands anchoring the sciatic nerve to the surrounding muscle or fascial planes, was present in 25 specimens (20.8%) overall. It was not, however, distributed evenly between normal and variant anatomy.

Among the 98 specimens with Type 1 anatomy, tethering was seen in 14, a prevalence of 14.3%. The bands in these cases usually lay at the inferior border of the piriformis,

where the nerve emerges from the infrapiriformis canal. They were thin and filmy, and on gentle probing they did not appreciably restrict the nerve. Some fascial investment therefore exists even in normal anatomy, but it is slight and unlikely on its own to cause clinically significant entrapment.

The picture in variant anatomy was quite different. Tethering was present in 15 of the 22 specimens with Types 2 to 5, a prevalence of 68.2%. These bands were also qualitatively different, being thicker, tougher, and more widely adherent to the nerve. In Type 2 specimens the tethering was usually at the point where the common fibular nerve pierced the muscle belly, with fibrous strands running from the muscle substance to the epineurium. In Type 3 specimens the bands lay along the superior border of the muscle, where the common fibular nerve passed above it. In Type 4 specimens the bifid muscle formed a fibromuscular tunnel around the nerve, with bands bridging the two bellies. The single Type 5 specimen was tethered in both places, at the superior border for the common fibular nerve and within the muscle belly for the tibial nerve.

On chi-square testing the association between variant anatomy and tethering was highly significant ($p < 0.001$). Specimens with variant anatomy carried a 4.7-fold risk of significant tethering compared with normal anatomy (relative risk = 4.7; 95% confidence interval 2.8 to 7.9). This supports our hypothesis that variations in the sciatic nerve-piriformis relationship predispose to fibrovascular entrapment bands.

Finding tethering in almost 70% of variant specimens suggests these configurations are more than incidental observations and represent a structural predisposition to entrapment. The bands are most likely secondary, developing as a fibrotic response to chronic microtrauma or friction between the nerve and the variant muscle around it. With time they may thicken and become more restrictive, and so contribute to the symptoms of deep gluteal syndrome [6].

For the surgeon, a 4.7-fold risk means that tethering should be expected in patients with known or suspected variant anatomy, and that dissection has to be careful enough to release every constricting element. Bands left behind may leave the decompression incomplete and the symptoms unchanged, even when the piriformis tendon has been released adequately [7].

The findings of this clinical correlation analysis are summarized in Table 4, which presents the prevalence of fibrovascular tethering in normal versus variant anatomy along with the calculated relative risk.

TABLE 4 | Association between anatomical variation and fibrovascular tethering.

Anatomy Type	Specimens with tethering (n)	Total specimens (n)	Prevalence (%)	Relative risk	p-value
Normal (Type 1)	14	98	14.3	Reference	-
Variant (Types 2-5)	15	22	68.2	4.7	< 0.001

Taken together, these results give a quantitative basis for adjusting surgical technique when the anatomy is variant. Fascial release is reasonable in all patients undergoing endoscopic decompression, but a more thorough release is justified once a variant has been identified before or during operation. The relative risk of 4.7 is also useful in counselling, as it gives patients a sense of how likely extensive release will be, and it helps in planning for a longer operation and a wider dissection [2].

4 | Discussion

The main practical message of this study concerns how much fascial release is needed when the anatomy is variant. A 4.7-fold risk of fibrovascular tethering is a large enough difference to justify altering the standard endoscopic

technique. Where a Beaton and Anson Type 2 to Type 5 configuration is recognised, whether on preoperative magnetic resonance imaging or at exploration, the operation should be planned as a wider dissection that addresses every potential tethering point rather than as a routine piriformis tendon release. In Type 2, for instance, the surgeon should be ready to perform a partial myotomy to free the common fibular nerve from its intramuscular course; in Type 4 the two bellies of the bifid muscle must be separated before the nerve is fully decompressed. These are specific and modest changes to technique, and they would apply to roughly one patient in five. The difference in tethering between variant and normal anatomy in our specimens was substantial, 68.2% against 14.3%, which points to a considerably greater risk of entrapment within the deep gluteal space when a variant is present (Figure 3).

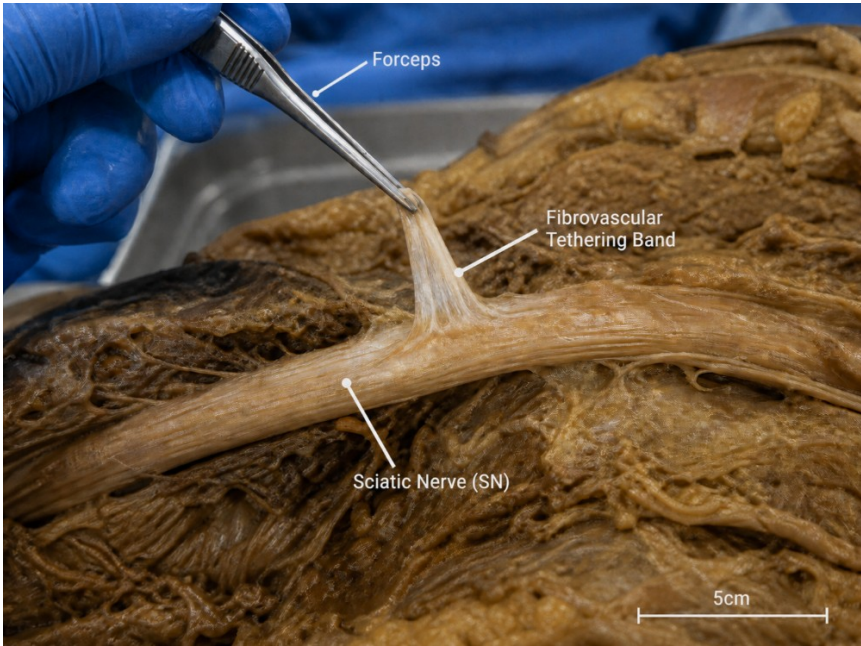


FIGURE 3 | High-magnification gross anatomical photograph showing surgical forceps elevating a dense fibrovascular tethering band that compresses and tethers the sciatic nerve against the deep gluteal fascia in a variant anatomical specimen.

Our topographic measurements are useful in a more ordinary way. The sciatic nerve sat about 27 to 29 mm from both the ischial tuberosity and the greater trochanter, which gives surgeons a reference for planning portal trajectories and reduces the chance of injuring the nerve while introducing instruments. Since the two sides did not differ, the same approach can be used bilaterally. The variability of three to four millimetres within each measurement is a reminder that individual imaging still has a place. In this way the topographic data complement the morphometric findings, turning anatomical description into landmarks that can be used in the operating room.

Our morphometric values sit close to those already published. A South African series of 170 cadavers gave a mean piriformis length of 82.3 mm and a mean sciatic nerve

width of 14.7 mm at the level of the greater sciatic foramen, with clear sex differences in the muscle [8], both within a few millimetres of the 84.5 ± 7.2 mm and 15.8 ± 2.4 mm recorded here. A separate analysis of 43 formalin-fixed cadavers reported 28.5 mm from the lateral border of the nerve to the greater trochanter and 26.8 mm from the medial border to the ischial tuberosity [9], again close to the 29.4 ± 3.8 mm and 27.2 ± 3.5 mm measured on the right in this cohort. What those series did not do was collect the measurements alongside variant anatomy or tethering, which is the gap the present study addresses.

Several limitations should be kept in mind. The most fundamental is that this is cadaveric work: formalin fixation alters tissue properties, including the elasticity and tensile strength of nerve and muscle. The bands we identified may

look stiffer and more prominent than they would in living tissue, so their clinical importance could be overestimated. The sample of 120 gluteal regions was adequate for the common variants but too small to estimate the frequency of rare ones, such as Type 5, which appeared once. Type 6 did not appear at all, which does not mean it does not exist; its true prevalence remains uncertain. Finally, a cross-sectional design says nothing about how tethering develops over time, so we cannot tell whether these bands form progressively or are present from birth.

Several lines of further work follow from this. The most important is prospective clinical study linking preoperative imaging to intraoperative findings and postoperative outcomes in patients having endoscopic gluteal decompression, which would test whether the relative risk of 4.7 holds outside the dissection room and whether more extensive release in variant anatomy actually improves pain, function, and revision rates. Longitudinal imaging with high-resolution magnetic resonance neurography could follow asymptomatic people with variant anatomy and show whether tethering develops over time. Biomechanical studies on fresh-frozen cadavers or computational models could measure the compressive forces acting on the nerve in each configuration and explain why the risk is higher. It would also be worth asking whether routine preoperative screening for variant anatomy is cost-effective in reducing surgical failure, given how common these variants are.

5 | Conclusion

In this cadaveric series, anatomical variations in the sciatic nerve-piriformis relationship classified by the Beaton and Anson system occurred in 18.3% of gluteal regions and carried a 4.7-fold risk of fibrovascular tethering compared with normal anatomy. The morphometric data place the sciatic nerve consistently about 27 to 29 mm from the ischial tuberosity and the greater trochanter, which gives a workable landmark for portal placement in endoscopic decompression. These findings address the gap between describing variant anatomy and quantifying what it means, and they support our hypothesis that variant configurations predispose to clinically relevant tethering. To our knowledge this is the first relative risk estimate for that association, which moves anatomical variation from an incidental observation towards a surgical risk factor.

The implications are directly usable. Surgeons performing endoscopic gluteal decompression should expect fibrovascular tethering in close to 70% of patients with variant anatomy and should plan a fascial release that goes beyond simple division of the piriformis tendon. The topographic distances reported here give reference points for portal placement that may help avoid iatrogenic nerve injury. What is needed next is prospective clinical validation, correlating preoperative imaging with intraoperative findings and postoperative outcomes, to establish whether targeted fascial release in these patients improves recovery and lowers revision rates. For now, the practical point for surgeons managing deep gluteal syndrome is that variant anatomy is a useful predictor of fibrovascular entrapment and warrants a more extensive approach if decompression is to be complete.

Declarations

Authors' declaration. All named authors contributed to the design of the study, the acquisition or interpretation of the data, and the drafting or critical revision of the manuscript. All authors have read and approved the final version and accept responsibility for its content. The manuscript is original, has not been published elsewhere, and is not under consideration by another journal.

Conflict of interest. The authors declare that they have no competing financial or personal interests that could have influenced the work reported in this article.

Use of artificial intelligence. No artificial intelligence tools were used in the preparation of this manuscript. The text was not generated, rewritten or language-polished by any AI system, and no AI tool was used in the dissection protocol, the measurements, the statistical analysis or the interpretation of the results.

References

- Hernando MF, Cerezal L, Pérez-Carro L, Abascal F, Canga A. Deep gluteal syndrome: anatomy, imaging, and management of sciatic nerve entrapments in the subgluteal space. *Skeletal Radiol.* 2015;44(7):919-934. doi:10.1007/s00256-015-2124-6
- Carro LP, Hernando MF, Cerezal L, Navarro IS, Fernandez AA, Castillo AO. Deep gluteal space problems: piriformis syndrome, ischiofemoral impingement and sciatic nerve release. *Muscles Ligaments Tendons J.* 2016;6(3):384-396. doi:10.11138/mltj/2016.6.3.384
- Kizaki K, Uchida S, Shanmugaraj A, et al. Deep gluteal syndrome is defined as a non-discogenic sciatic nerve disorder with entrapment in the deep gluteal space: a systematic review. *Knee Surg Sports Traumatol Arthrosc.* 2020;28(10):3354-3364. doi:10.1007/s00167-020-05966-x
- Poutoglidou F, Piagkou M, Totlis T, Tzika M, Natsis K. Sciatic nerve variants and the piriformis muscle: a systematic review and meta-analysis. *Cureus.* 2020;12(11):e11531. doi:10.7759/cureus.11531
- Tomaszewski KA, Graves MJ, Henry BM, et al. Surgical anatomy of the sciatic nerve: a meta-analysis. *J Orthop Res.* 2016;34(10):1820-1827. doi:10.1002/jor.23186
- Hopayian K, Danielyan A. Four symptoms define the piriformis syndrome: an updated systematic review of its clinical features. *Eur J Orthop Surg Traumatol.* 2018;28(2):155-164. doi:10.1007/s00590-017-2031-8
- Martin HD, Reddy M, Gómez-Hoyos J. Deep gluteal syndrome. *J Hip Preserv Surg.* 2015;2(2):99-107. doi:10.1093/jhps/hnv029
- Bergsteed BJ. *The Sciatic Nerve Division in the Gluteal Region in a South African Population: An Anatomical Study* [MSc thesis]. Stellenbosch, South Africa: Stellenbosch University; 2019. <http://hdl.handle.net/10019.1/105909>
- Asmall T, Gunston G, Venter R, Henry BM, Keet K. Surgical anatomy of the sciatic nerve and its relationship to the piriformis muscle with a description of a rare variant. *SA Orthop J.* 2020;19(1):33-39. doi:10.17159/2309-8309/2020/v19n1a5