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Anatomical variability of the femoral neurovascular bundle below the inguinal ligament: a cadaveric study with implications for vascular access

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Abstract

Purpose

The femoral triangle is a key region for vascular access, but the spatial relationships between the femoral artery (FA), femoral vein (FV) and femoral nerve (FN) may vary below the inguinal ligament (IL). This cadaveric study evaluated the anatomical variability of the femoral neurovascular bundle at three predefined levels below the IL.

Methods

Twenty lower limbs from 10 formalin-fixed adult Caucasian cadavers were examined. Measurements were performed at three levels below the IL: L1, 1 cm; L2, 5 cm; and L3, 10 cm. The FA–FV relationship, FN–FA distance, safe zone width, external FA diameter and origin of the profunda femoris artery (PFA) were assessed.

Results

The safe zone decreased from 11.73 ± 3.53 mm at L1 to 9.64 ± 4.04 mm at L2 and 2.32 ± 2.13 mm at L3. Significant FA/FV overlap increased from 1/20 limbs at L1 to 18/20 limbs at L3. The external FA diameter decreased from 10.22 ± 2.38 mm at L1 to 8.40 ± 1.38 mm at L3. The mean FA_0–PF_0 distance was 4.48 ± 2.02 cm. L2 was located below the PFA origin in 15/20 limbs and L3 in all limbs.

Conclusion

The topography of the femoral neurovascular bundle changes substantially within the first 10 cm below the IL. More distal levels are associated with increased FA/FV overlap, a narrower safe zone and greater anatomical heterogeneity. Individual anatomical assessment, preferably with imaging guidance, remains important when planning safe femoral vascular access.

1. Introduction

The femoral triangle is a clinically important anatomical region that contains the femoral artery (FA), femoral vein (FV) and femoral nerve (FN). In classical anatomical descriptions, these structures are arranged from lateral to medial as FN, FA and FV [1]. This relationship provides the anatomical basis for numerous procedures performed in vascular surgery, interventional cardiology, cardiac surgery, emergency medicine and regional anaesthesia [19, 21]. Femoral vascular access remains widely used for diagnostic and therapeutic procedures. Safe arterial access usually requires puncture of the common FA below the inguinal ligament (IL) and above the femoral bifurcation, whereas venous access depends

on reliable identification of the FV in relation to the FA [5, 19]. Most available studies have focused mainly on the FA–FV relationship [2, 4, 9, 10].

Less attention has been paid to the combined topography of the FA, FV and FN at fixed levels below the IL, especially in relation to the origin of the profunda femoris artery (PFA). This is important because the proximal femoral region is not a uniform anatomical corridor, and its neurovascular relationships may change within the first centimetres below the IL [4, 5, 10].

The aim of the present cadaveric study was to evaluate the anatomical variability of the femoral neurovascular bundle below the IL at three predefined levels. Specifically, we assessed the FA–FV relationship, the FN–FA distance, the width of the safe zone between the FV and FN, the external diameter of the FA, and the position of the measurement levels relative to the origin of the PFA. The findings were analysed with particular reference to their potential relevance for femoral vascular access.

2. Material and methods

2.1. Study design and anatomical material

This cadaveric anatomical study was performed on 20 lower limbs from 10 adult Caucasian cadavers obtained through the Conscious Body Donation Program conducted by the Department of Human Anatomy, Medical University of Silesia in Katowice. The study material included 7 male and 3 female cadavers, aged 74–91 years, corresponding to 14 male and 6 female lower limbs. The analysed material included 10 right and 10 left lower limbs.

All specimens were formalin-fixed. Each femoral region was analysed separately. The exclusion criteria were evidence of previous surgery in the inguinal or femoral region, traumatic disruption, gross anatomical deformity, or damage to the FA, FV, FN or PFA. No specimens met these exclusion criteria; therefore, all examined lower limbs were included in the final analysis.

2.2. Dissection procedure

The femoral triangle was exposed by classical layer-by-layer dissection. The skin, subcutaneous tissue, superficial fascia, fascia lata and femoral sheath were carefully removed. The FA, FV and FN were identified and exposed completely to a level distal to the most distal measurement point. The lower limb was maintained in the anatomical position during dissection and measurements. Care was taken to preserve the native topographical relationships of the femoral vessels and FN. The general arrangement of the femoral neurovascular structures after dissection is presented in Fig. 1.

2.3. Anatomical landmarks and measurement levels

The IL was defined as the line connecting the anterior superior iliac spine and the pubic tubercle. The FA reference point, designated as FA_0, was defined as the centre of the FA at the level of the inferior border

of the IL, corresponding to the transition of the external iliac artery into the FA. The three predefined measurement levels used in the study are presented in Table 1.

Table 1
Measurement levels below the inguinal ligament.

Level	Definition
L1	1 cm below the inguinal ligament
L2	5 cm below the inguinal ligament
L3	10 cm below the inguinal ligament

At each level, the FA, FV and FN or its visible branches were assessed. The anatomical landmarks and predefined measurement levels are demonstrated in Fig. 2.

2.4. Measurement protocol

Prior to the measurements, each FA was inspected to ensure that it was not bent, flattened or unnaturally stretched. All measurements were performed using a digital caliper with an accuracy of ± 0.02 mm. Each linear measurement was repeated three times consecutively, and the arithmetic mean of the three measurements was used for analysis. All morphometric measurements were performed by the same investigator to ensure measurement consistency and comparability. The FA–FV relationship was assessed independently by two observers, and any discrepancies were resolved by consensus.

At each level, the following parameters were recorded: FA–FV relationship type, FN–FA distance, safe zone width and external diameter of the FA. For the purposes of these measurements, FA referred to the main arterial trunk present at a given level: the common femoral artery proximal to the origin of the PFA and the superficial femoral artery distal to the origin of the PFA. The FN–FA distance was defined as the shortest straight-line distance between the nearest external wall of the FA and the nearest edge of the FN or its closest visible branch. The safe zone was defined as the distance between the lateral border of the FV and the medial border of the FN or its closest visible branch. For descriptive purposes, the number of cases with a safe zone below 5 mm was recorded. This threshold was used as an anatomical descriptive category and not as a validated procedural cut-off. The external diameter of the FA was measured perpendicular to the visible long axis of the artery.

2.5. Femoral artery-femoral vein relationship

The FA–FV relationship was assessed from above at each measurement level as the projected topographical overlap of the FA over the FV. Four relationship types were distinguished, as shown in Table 2.

Table 2
Classification of femoral artery–femoral vein relationship types.

Type	Definition
Type I	The femoral artery lies completely lateral to the femoral vein, without overlap.
Type II	The femoral artery partially overlaps the femoral vein, involving ≤ 50% of the femoral artery width.
Type III	The femoral artery markedly overlaps the femoral vein, involving > 50% of the femoral artery width.
Type IV	The femoral artery lies anterior to the femoral vein, practically covering the vein.

The classification was modified based on Bhatia et al. [4] by adding type IV. For additional analysis, types III and IV were grouped as significant vessel overlap. The four relationship types are shown schematically in Fig. 3.

2.6. Origin of the profunda femoris artery

The origin of the PFA was identified as the first distinct branching point from the FA. The proximal and distal margins of the origin were identified, and the midpoint between them was designated as PF_0. The distance from FA_0 to PF_0 was measured in a straight line using a digital caliper and expressed in centimetres. The origin of the PFA was classified according to the FA_0–PF_0 distance, as shown in Table 3.

Table 3
Classification of the origin of the profunda femoris artery according to the FA_0–PF_0 distance.

Type	Definition
Type A	High origin, ≤ 3.0 cm from FA_0
Type B	Intermediate origin, > 3.0 to ≤ 5.0 cm from FA_0
Type C	Low origin, > 5.0 cm from FA_0

Each measurement level was also classified as being located either above or below PF_0. An example of the identification and measurement of the PFA origin is shown in Fig. 4.

2.7. Statistical analysis

Statistical analysis was performed using Python 3.11 with the SciPy and statsmodels libraries. Continuous variables were presented as mean ± standard deviation (SD), median, interquartile range (IQR) and range. Categorical variables were presented as counts and percentages. Comparisons between L1, L2 and L3 were performed using the Friedman test. When significant differences were found

for continuous variables, post-hoc pairwise comparisons were performed using the Wilcoxon signed-rank test with Holm correction. The frequency of significant FA/FV overlap, defined as type III or IV, and the frequency of a safe zone below 5 mm were compared between levels using Cochran's Q test. A p-value below 0.05 was considered statistically significant.

3. Results

All 20 examined lower limbs were included in the final analysis. Complete data were obtained at L1, L2 and L3 in each specimen. The FN–FA distance differed significantly between the three measurement levels in the overall comparison. The mean distance was 4.73 ± 2.31 mm at L1, 5.84 ± 2.83 mm at L2 and 3.85 ± 2.79 mm at L3 (p = 0.026). However, post-hoc pairwise comparisons did not remain significant after Holm correction. The safe zone width decreased from 11.73 ± 3.53 mm at L1 to 9.64 ± 4.04 mm at L2 and 2.32 ± 2.13 mm at L3. The difference between levels was statistically significant (p < 0.001). Post-hoc analysis with Holm correction confirmed significant differences between all measurement levels. A safe zone below 5 mm was not observed at L1, was present in 2 cases at L2 and in 17 cases at L3. The external diameter of the FA also decreased significantly between levels. The mean diameter was 10.22 ± 2.38 mm at L1, 8.90 ± 1.46 mm at L2 and 8.40 ± 1.38 mm at L3 (p = 0.001). Post-hoc analysis showed significant differences between L1 and L2 and between L1 and L3, whereas the difference between L2 and L3 was not significant. Quantitative measurements are shown in Table 4.

Table 4
Quantitative measurements at the three levels below the inguinal ligament.

Parameter	L1, 1 cm	L2, 5 cm	L3, 10 cm	p-value
FN–FA distance, mm	4.73 ± 2.31	5.84 ± 2.83	3.85 ± 2.79	0.026
Median; IQR	4.41; 3.34–6.16	5.08; 4.16–7.06	3.02; 1.98–5.06	
Range	0.98–10.52	0.79–12.70	0.00–12.80	
Safe zone, mm	11.73 ± 3.53	9.64 ± 4.04	2.32 ± 2.13	< 0.001
Median; IQR	11.67; 8.40–13.64	8.72; 7.40–12.96	1.75; 0.45–4.04	
Range	6.56–18.72	0.00–16.59	0.00–6.58	
Safe zone < 5 mm, n (%)	0/20 (0.0%)	2/20 (10.0%)	17/20 (85.0%)	< 0.001
External FA diameter, mm	10.22 ± 2.38	8.90 ± 1.46	8.40 ± 1.38	0.001
Median; IQR	10.47; 9.19–10.61	8.98; 8.14–9.26	8.30; 8.29–8.89	
Range	6.16–14.80	5.91–13.01	4.90–10.87	

Values are presented as mean ± standard deviation unless otherwise stated. FA, femoral artery; FN, femoral nerve; IQR, interquartile range.

The FA–FV relationship changed between the three measurement levels. At L1, type I was observed in 17 cases and was the dominant pattern. At L2, type I remained the most frequent pattern, but types II–IV were more common than at L1. At L3, type IV was the most frequent pattern and was observed in 11 cases. Significant FA/FV overlap, defined as type III or type IV, was observed in 1 case at L1, 4 cases at L2 and 18 cases at L3. The difference between levels was statistically significant (Cochran's Q = 27.44, $p < 0.001$). The distribution of FA–FV relationship types is shown in Table 5.

Table 5
Distribution of FA/FV relationship types at L1, L2 and L3.

Level	Type I	Type II	Type III	Type IV	Type III–IV
L1	17/20 (85.0%)	2/20 (10.0%)	1/20 (5.0%)	0/20 (0.0%)	1/20 (5.0%)
L2	10/20 (50.0%)	6/20 (30.0%)	2/20 (10.0%)	2/20 (10.0%)	4/20 (20.0%)
L3	1/20 (5.0%)	1/20 (5.0%)	7/20 (35.0%)	11/20 (55.0%)	18/20 (90.0%)

FA, femoral artery; FV, femoral vein.

The PFA originated at a mean distance of 4.48 ± 2.02 cm from FA_0. The median FA_0–PF_0 distance was 4.19 cm, with an IQR of 3.41–5.07 cm and a range from 0.97 to 9.81 cm. According to the adopted classification, type B origin was the most frequent pattern and was observed in 11/20 limbs (55.0%). Type A origin was found in 4/20 limbs (20.0%) and type C origin in 5/20 limbs (25.0%). L1 was located below PF_0 in 1/20 limbs (5.0%). L2 was located below PF_0 in 15/20 limbs (75.0%), whereas L3 was below PF_0 in all examined lower limbs (20/20, 100.0%). Consequently, in these cases, measurements at the corresponding levels referred to the arterial trunk distal to the PFA origin. Data on the origin of the PFA and the relationship of the measurement levels to PF_0 are shown in Table 6.

Table 6
Profunda femoris artery origin and position of measurement levels relative to PF_0.

Parameter	Result
Number of analysed lower limbs	20
FA_0–PF_0 distance, mean ± SD	4.48 ± 2.02 cm
FA_0–PF_0 distance, median; IQR	4.19; 3.41–5.07 cm
FA_0–PF_0 distance, range	0.97–9.81 cm
Type A, high origin, ≤ 3.0 cm	4/20 (20.0%)
Type B, intermediate origin, > 3.0 to ≤ 5.0 cm	11/20 (55.0%)
Type C, low origin, > 5.0 cm	5/20 (25.0%)
L1 located below PF_0	1/20 (5.0%)
L2 located below PF_0	15/20 (75.0%)
L3 located below PF_0	20/20 (100.0%)

FA_0, femoral artery reference point at the inferior border of the inguinal ligament; PF_0, origin of the profunda femoris artery; SD, standard deviation; IQR, interquartile range.

4. Discussion

4.1. Main findings

The present study provides anatomical data on the variability of the femoral neurovascular bundle below the IL. The findings indicate that the first 10 cm below the IL should not be regarded as a uniform anatomical region, because the spatial relationships between the FA, FV and FN change substantially in the proximal-to-distal direction.

The anatomically defined safe zone, measured as the distance between the lateral border of the FV and the medial border of the FN or its closest visible branch, decreased from 11.73 ± 3.53 mm at L1 to 9.64 ± 4.04 mm at L2 and 2.32 ± 2.13 mm at L3. This indicates a progressive reduction in the space separating the FV from the FN or its nearest visible branch. Accordingly, L1 showed the most favourable anatomical configuration in the analysed segment. This finding is consistent with previous reports describing variability in FN position and branching within the femoral triangle [14, 20].

A distal increase in FA/FV overlap was also observed. Significant overlap, defined as type III or IV, was present in 1/20 limbs at L1 (5.0%), 4/20 limbs at L2 (20.0%) and 18/20 limbs at L3 (90.0%). Thus, the vascular relationship changed from a predominantly lateral–medial arrangement proximally to a more overlapping, anterior–posterior configuration distally. A similar tendency has been reported by Bhatia et

al., who observed an increase in FA/FV overlap in children between 1 cm and 3 cm below the IL [4]. Mat Taib et al. also described variability in the level at which the FA crosses the FV, with this crossing occurring at different levels along the proximal-to-distal axis [13]. In the present study, only 2/20 limbs (10.0%) at L3 did not show significant overlap, confirming interindividual variability in the crossing level of these vessels.

The origin of the PFA was another important determinant of the anatomical interpretation of the measurement levels. The mean FA_0–PF_0 distance was 4.48 ± 2.02 cm, with a median of 4.19 cm and a range of 0.97–9.81 cm. Therefore, in many limbs, L2 and L3 were located below the origin of the PFA. This may be associated with the more frequent FA/FV overlap observed at distal levels, because these points may correspond not only to a greater distance from the IL but also to a different arterial segment. In the present material, L1 most often represented the proximal/common FA level and showed a type I FA–FV relationship in 17/20 limbs (85.0%), whereas more distal levels more frequently corresponded to the superficial femoral artery segment distal to the origin of the PFA.

Overall, these findings show that the topography of the femoral neurovascular bundle changes markedly within the first 10 cm below the IL. Interpretation of fixed measurement levels should therefore take into account not only their distance from the IL, but also the individual level of PFA origin and the associated changes in vascular and neural relationships.

4.2. Femoral artery–femoral vein relationship and overlap

The FA–FV relationship changed markedly along the proximal-to-distal axis. Although the FV is classically described as lying medial to the FA, this arrangement was most consistent at the proximal level. At L1, significant FA/FV overlap, defined as type III or IV, was present in only 1/20 limbs (5.0%). This increased to 4/20 limbs (20.0%) at L2 and 18/20 limbs (90.0%) at L3, indicating a progressive shift from a lateral–medial to a more overlapping, anterior–posterior vascular configuration.

Previous imaging studies support the variability of the FA–FV relationship and, in several reports, its distal change. Baum et al. demonstrated substantial variability in the anatomical relationship between the common femoral artery and common femoral vein on computed tomography, including frequent overlap between the two vessels [2]. Hughes et al. similarly reported that both the frequency and degree of FA/FV overlap increased distally, whereas the side-by-side arrangement was most common close to the IL [9]. Bhatia et al. observed the same tendency in children, with overlap increasing between 1 cm and 3 cm below the IL [4]. Lee et al. also showed that overlap between the common femoral artery and common femoral vein increased with increasing distance from the IL [10], and Beaudoin et al. reported clinically relevant femoral vessel overlap in the context of femoral venous cannulation [3].

The present cadaveric findings are also compatible with the dissection-based observations of Mat Taib et al., who reported that the FA may cross the FV at different levels along the femoral triangle and, in some cases, more distally toward the adductor canal [13]. Taken together, these findings indicate that,

for access planning, the classical medial position of the FV relative to the FA should be regarded as a proximal reference pattern rather than a fixed relationship throughout the upper thigh.

4.3. Safe zone and relation to the femoral nerve

The safe zone was defined as the distance between the lateral border of the FV and the medial border of the FN or its closest visible branch. This parameter should be interpreted as an anatomical descriptor rather than as an established clinical cut-off. In the present study, the safe zone decreased from 11.73 ± 3.53 mm at L1 to 9.64 ± 4.04 mm at L2 and 2.32 ± 2.13 mm at L3. In addition, a safe zone below 5 mm was absent at L1, present in 2/20 limbs (10.0%) at L2 and present in 17/20 limbs (85.0%) at L3. These findings indicate a progressive reduction in the anatomical space between the FV and the FN or its nearest visible branch at more distal levels.

This reduction may be related not only to the distal convergence of the neurovascular structures, but also to the branching pattern of the FN. Muhly and Orebaugh emphasized the importance of ultrasound assessment of the FN and adjacent vessels at the femoral crease, highlighting the variability of their anatomical relationships in this region [15]. Lonchena et al. showed that FN branching may occur relatively proximally, with a mean branching distance of 3.9 cm below the IL [11]. Additional reports have also highlighted variability in FN location within the femoral triangle, including case-based anatomical observations and ultrasound-based analyses relevant to guided procedures [14, 20].

Consequently, at more distal levels, the structure closest to the FV may not be the main FN trunk, but one of its branches. This is consistent with the measurement protocol used in the present study, in which the closest visible branch was included in the definition of both the FN–FA distance and the safe zone. This may partly explain the marked decrease in the measured safe zone from L1 to L3 and supports the interpretation of the safe zone as a level-dependent anatomical parameter.

4.4. Profunda femoris origin and interpretation of L2/L3

The level of PFA origin is essential for interpreting the measurement levels used in the present study. The mean FA_0–PF_0 distance was 4.48 ± 2.02 cm, with a median of 4.19 cm and a range of 0.97–9.81 cm. This indicates that, although the PFA most often originated several centimeters below the IL, individual variability was substantial.

These findings are broadly consistent with previous anatomical studies reporting that the PFA usually originates within a few centimeters below the IL or the mid-inguinal point, although the reference points used for measurement differ between studies. Nasr et al. reported that the PFA most commonly arose from the posterolateral aspect of the FA, with a mean origin distance of approximately 49–52 mm from the mid-inguinal point, depending on sex and side [16]. Manjappa and Prasanna reported a mean origin distance of approximately 3.2–3.6 cm from the mid-inguinal point and emphasized the clinical relevance of PFA variability [12]. More recently, de Villiers and Keet also confirmed substantial variability in the origin and branching pattern of the PFA [7].

In the present study, intermediate origin was the most frequent pattern, occurring in 11/20 limbs (55.0%), whereas high and low origins were observed in 4/20 limbs (20.0%) and 5/20 limbs (25.0%), respectively. This variability affected the anatomical interpretation of fixed measurement levels. L2, located 5 cm below the IL, was already below the origin of the PFA in 15/20 limbs (75.0%), whereas L3 was below this origin in all examined limbs (20/20, 100.0%). Therefore, L2 should not be automatically interpreted as a common FA level; in most cases, it corresponded to the superficial femoral artery segment distal to the origin of the PFA.

Consequently, the differences observed between L1, L2 and L3 should be understood not only as a proximal-to-distal change, but also as a transition from the arterial segment proximal to the PFA origin to the segment distal to it. This is particularly important for L2, which represented a transitional and anatomically heterogeneous level in the present material.

4.5. Clinical implications for vascular surgery, interventional cardiology and cardiac surgery

The findings of the present study may have practical anatomical relevance for procedures requiring femoral vascular access, particularly in vascular surgery, interventional cardiology and cardiac surgery. The first 10 cm below the IL should not be regarded as a uniform access region. More distal levels were associated with a higher frequency of FA/FV overlap, a narrower safe zone, a smaller external FA diameter, and a greater likelihood of being located below the origin of the PFA.

In the present material, L1 showed the most favourable anatomical configuration. At this level, type I FA–FV relationship was observed in 17/20 limbs (85.0%), significant overlap was present in only 1/20 limbs (5.0%), and the safe zone was widest, measuring 11.73 ± 3.53 mm. By contrast, L3 showed a less favourable combination of findings, including significant FA/FV overlap in 18/20 limbs (90.0%), type IV relationship in 11/20 limbs (55.0%), and a markedly reduced safe zone of 2.32 ± 2.13 mm. The external FA diameter also decreased from 10.22 ± 2.38 mm at L1 to 8.90 ± 1.46 mm at L2 and 8.40 ± 1.38 mm at L3.

These findings provide an anatomical rationale for caution with excessively distal puncture sites when common FA access is intended. Cilingiroglu et al. emphasized that femoral arterial access should ideally target the anterior wall of the common FA below the IL and above the bifurcation, particularly during procedures requiring large-bore sheaths; they also noted that overly proximal or overly distal punctures may be associated with access-related complications [6]. In the present study, L2 was already below the origin of the PFA in 15/20 limbs (75.0%), whereas L3 was below it in all limbs (20/20, 100.0%). Thus, a fixed distance below the IL does not reliably identify the same arterial segment in all individuals.

This observation is consistent with radiographic evidence showing considerable variability in the relationship between the femoral head, IL and common FA bifurcation. Brahmandam et al. demonstrated that osseous landmarks have limited reliability for precisely identifying the intended common FA access zone [5]. In the present study, the FA_o–PF_o distance ranged from 0.97 to 9.81 cm, supporting the view

that surface or radiographic landmarks alone may correspond to different arterial segments in different individuals. The results should not be interpreted as defining a universally safe puncture point. Rather, they support individualized anatomical assessment of the femoral region before vascular access. Sato et al. emphasized the importance of understanding the spatial relationship between the FA and FV and the role of imaging in improving procedural safety [19]. Similarly, the meta-analysis by Huang et al. suggested potential benefits of ultrasound-guided FA puncture, including improved first-pass success, shorter access time and fewer complications, although the included studies were heterogeneous [8]. The present anatomical data may help explain these benefits: imaging allows assessment of the FA/FV relationship, identification of the IL and femoral bifurcation [22], and, when relevant, evaluation of adjacent neural structures before puncture.

4.6. Comparison between cadaveric and imaging studies

Cadaveric and imaging studies address related anatomical questions, but under different methodological conditions. Ultrasonography and computed tomography allow evaluation of the femoral vessels in vivo, with preserved vascular filling, blood flow and pressure-dependent changes; ultrasonographic assessment may also be influenced by limb position [17]. In contrast, cadaveric dissection allows direct visualization and measurement of the FA, FV, FN and PFA, but without physiological vessel filling or haemodynamic conditions.

These differences are particularly relevant when interpreting vessel diameter and FA/FV overlap. The FV is highly deformable in vivo and may change its calibre depending on venous pressure, respiration, muscle tone, limb position and external compression by the ultrasound probe [18]. In formalin-fixed cadaveric material, the vein may be partially collapsed and less compliant, which may influence absolute measurements, particularly venous calibre and FA/FV overlap. Therefore, the absolute values reported in cadaveric studies should not be regarded as directly interchangeable with imaging measurements.

Despite these limitations, the direction of change observed in the present study is consistent with imaging studies. Lee et al. reported that common femoral artery/common femoral vein overlap increased distally on computed tomography [10]. Bhatia et al. and Hughes et al. also described a distal increase in FA/FV overlap on ultrasonography [4, 9]. Thus, cadaveric and imaging studies should be regarded as complementary. Imaging reflects in vivo conditions, whereas dissection enables simultaneous direct assessment of the FA–FV relationship, FN proximity, safe zone width, external FA diameter in fixed specimens, and the level of PFA origin.

5. Limitations

This study has several limitations. First, it was performed on formalin-fixed cadaveric material; therefore, the measurements may not fully reflect in vivo conditions, including vascular pulsation, venous filling, vessel wall tension and physiological tissue compliance. In addition, dissection required exposure of the neurovascular structures, which may have reduced the influence of surrounding muscles and fascial planes on their spatial relationships.

Second, the sample size was limited to 20 lower limbs from 10 cadavers. Both lower limbs from the same cadavers were included; therefore, the observations should not be regarded as fully independent. The limited sample size also prevented meaningful subgroup analysis according to sex or side. The study material consisted of elderly Caucasian donors, which may limit the generalizability of the findings to younger individuals and other populations.

Third, the analysis was based on three predefined measurement levels below the IL. Although this allowed standardized comparison, it did not capture the continuous nature of anatomical changes along the femoral triangle. Variability in the level of PFA origin also affected the interpretation of fixed levels, because L2 and L3 did not always correspond to the same arterial segment.

Finally, at more distal levels, the closest neural structure was often a branch of the FN rather than the main trunk. This may influence interpretation of the FN–FA distance and safe zone width. The safe zone was an anatomical measurement defined for this study and should not be interpreted as a validated clinical safety threshold.

6. Conclusion

The topography of the femoral neurovascular bundle changes substantially within the first 10 cm below the IL. More distal levels were associated with increased FA/FV overlap, a narrower safe zone, a smaller external FA diameter and a greater likelihood of being located below the origin of the PFA. In the present material, L1 showed the most favorable anatomical configuration, whereas L3 was characterized by frequent significant FA/FV overlap and a markedly reduced safe zone. These findings indicate that fixed distances below the IL should not be assumed to represent equivalent anatomical conditions in all individuals. Individual anatomical assessment, preferably with imaging guidance, remains important when planning femoral vascular access.

Declarations

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Author contributions

LS: study design, dissection, measurements, data collection, statistical analysis, manuscript writing and editing. MS: dissection, discussion development, literature review, manuscript writing and editing. BP: dissection, literature review, manuscript writing and editing. WD: dissection, discussion development,

manuscript review and editing. KK: manuscript review and editing. KB: manuscript review and editing. TL: anatomical supervision, manuscript review and editing. GB: project supervision, anatomical consultation, manuscript review and editing. All authors read and approved the final manuscript.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare no competing interests.

Ethics approval

This study was performed on cadaveric material obtained through the Conscious Body Donation Program conducted by the Department of Human Anatomy, Medical University of Silesia in Katowice. The program has been conducted since 2003. All procedures were conducted in accordance with institutional regulations for anatomical research using donated human bodies.

Informed consent

All cadaveric specimens were obtained through the Conscious Body Donation Program conducted by the Department of Human Anatomy, Medical University of Silesia in Katowice. Written informed consent for the use of the bodies for scientific and educational purposes was provided by the donors during their lifetime.

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Figures

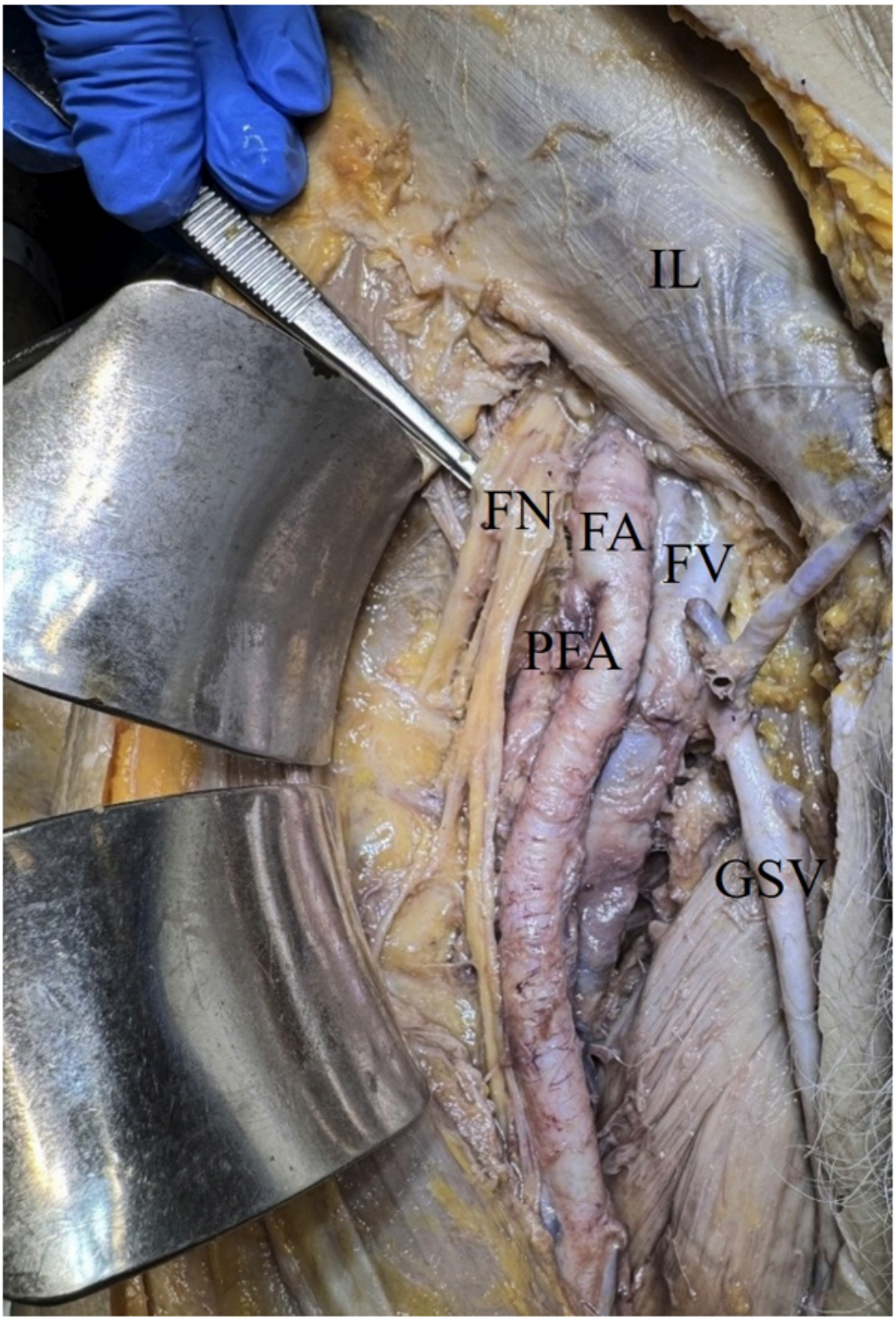


Figure 1

Cadaveric dissection of the femoral triangle. The sartorius muscle was retracted to expose the structures of the femoral triangle. FA, femoral artery; FV, femoral vein; FN, femoral nerve; PFA, profunda femoris artery; IL, inguinal ligament; GSV, great saphenous vein.

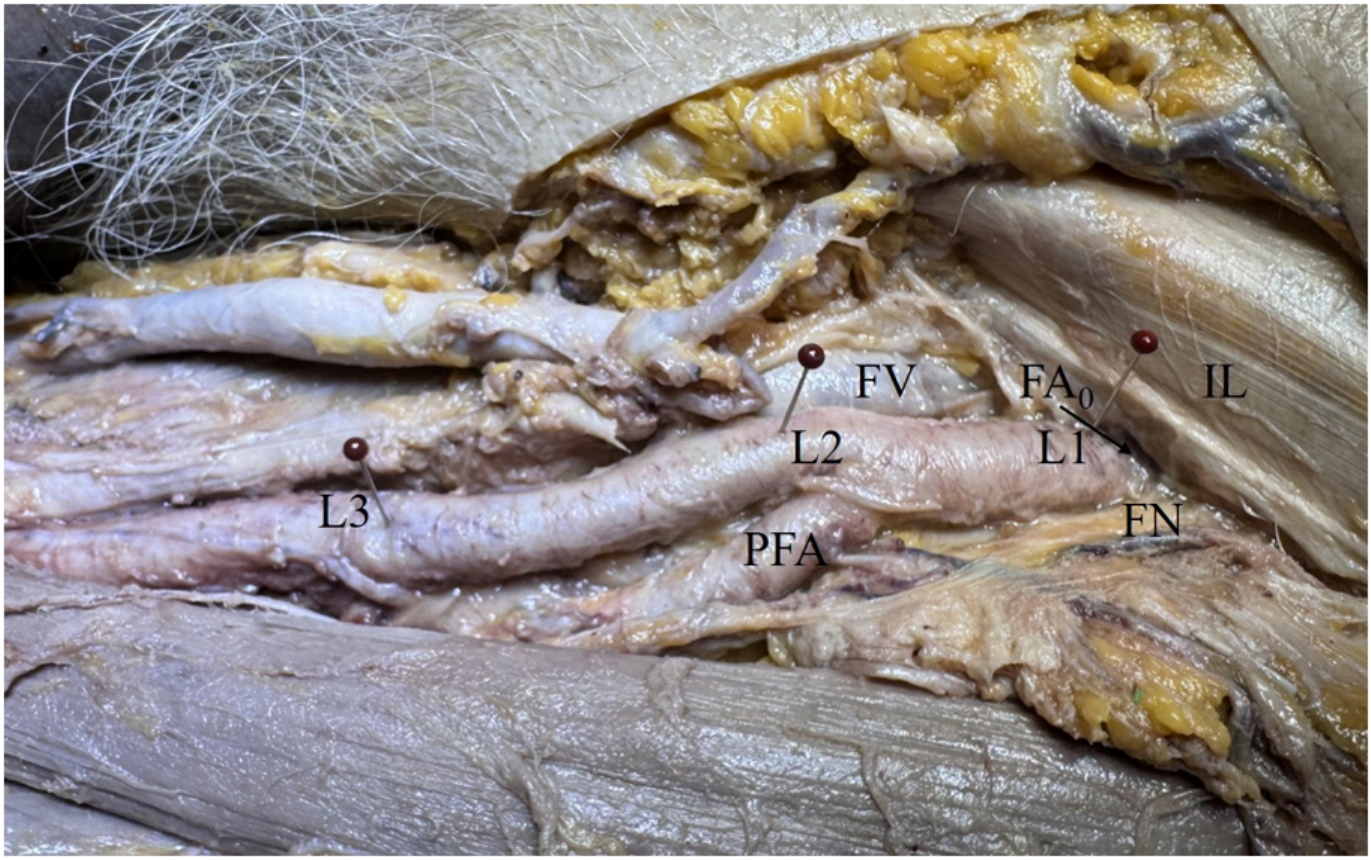


Figure 2

Cadaveric photograph showing the anatomical landmarks and measurement levels. IL, inguinal ligament; FA_0, femoral artery reference point; L1–L3, measurement levels; FV, femoral vein; FN, femoral nerve; PFA, profunda femoris artery.

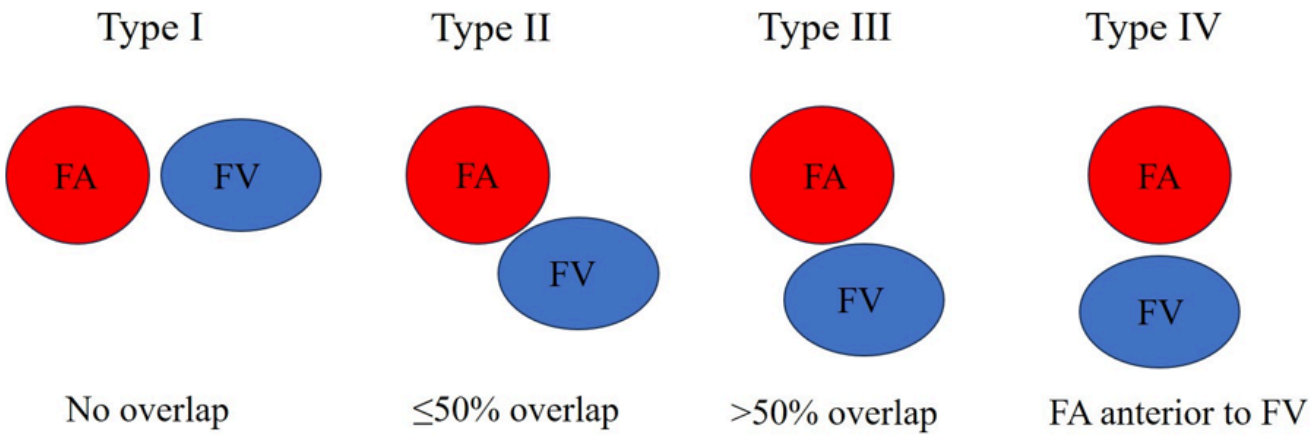


Figure 3

Schematic representation of the femoral artery–femoral vein relationship types. FA, femoral artery; FV, femoral vein. Modified based on: [4].

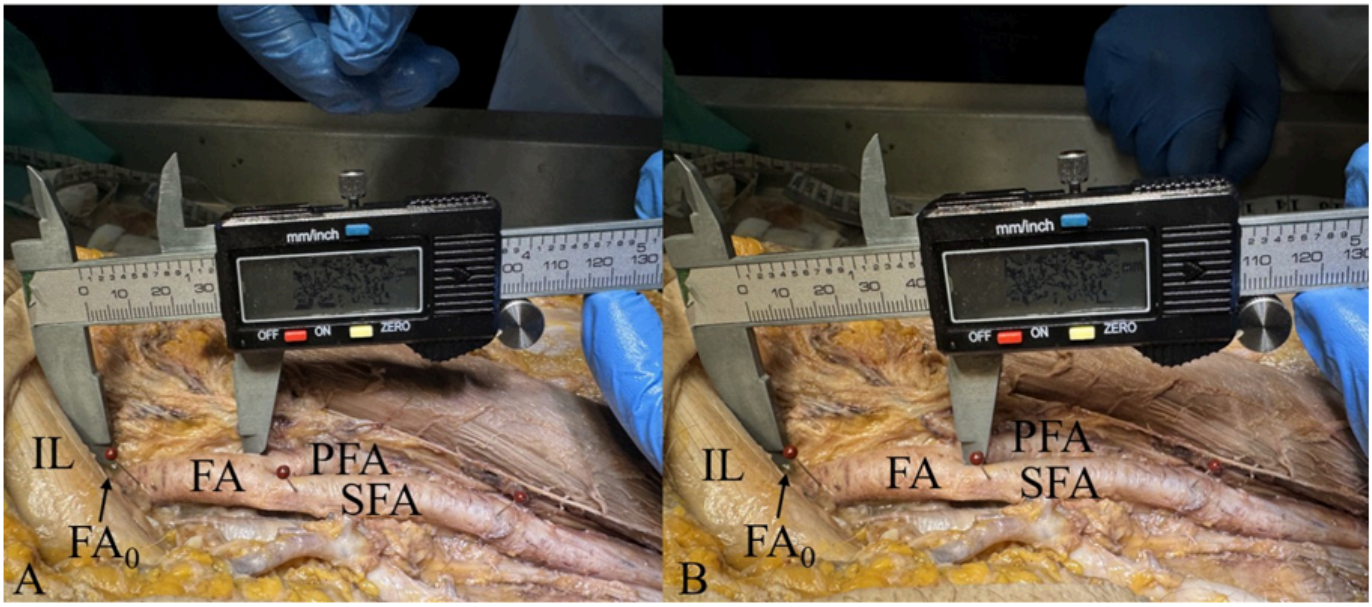


Figure 4

Identification and measurement of the origin of the profunda femoris artery. **A.** Measurement from FA_0 to the proximal margin of the origin of the profunda femoris artery. **B.** Measurement from FA_0 to the distal margin of the origin of the profunda femoris artery. FA, femoral artery; PFA, profunda femoris artery; SFA, superficial femoral artery; IL, inguinal ligament; FA_0, femoral artery reference point.