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Axial and sciatic arteries: a new interpretation

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Abstract

Introduction: The sciatic artery is rare anatomical vascular variation. it appear in the first trimester during pregnancy. It regresses as the femoral system develops. Failure of regression results in Axial or sciatic artery. **Methods:** In an investigation of 92 female and 79 male cadavers based on dissection, the persistent sciatic and axial arteries were identified and classified based on their origin and location.

Results: Sciatic arteries were observed to arise from a number of different arteries in 68 specimens: anterior trunk of the internal iliac artery (12 specimen); internal pudendal artery (1 specimen); posterior trunk of the internal iliac artery (44 specimens); anterior and posterior trunks as a double artery (4 specimens); superior gluteal artery (7 specimens). In addition, the sciatic arteries were observed to give the superior and inferior gluteal arteries (12 and 9 specimens respectively).

Discussion: This questions the general embryological origin of a persistent sciatic artery. The embryological origin of the proximal part of the axial artery and whether it forms the superior or inferior gluteal artery is discussed, together with the general arrangement of the internal iliac and femoral arterial systems. Presentation of the sciatic artery is also discussed with respect to existing embryological theories and from a new perspective. A number of embryological vascular anomalies are also discussed.

Conclusion: Understanding the vascular variability with coexistence of sciatic artery will alert radiologists to report them for surgeons, orthopaedics, and gynaecologists. This results in decrease the bleeding during and after operations.

Keyword: Axial theory, Sciatic theory, Superior gluteal, Inferior gluteal, internal Iliac, external iliac, superficial femoral, deep femora, common femoral, Internal pudendal.

Introduction

An anatomical variation in the blood supply to the sciatic nerve was observed by Green [1] which he referred to as a persistent sciatic artery. Persistent sciatic artery is a rare vascular malformation or anatomical anomaly resulting from a lack of regression of the embryonic dorsal axial (ischiatic) artery [2-26]. Embryologically, the 'proper umbilical artery' divides into two segments [27], with the proximal segment providing the vascular supply to the pelvis and lower limb and giving origin to the axial and iliac systems [4,28-31], while the distal segment becomes a fibrous cord, the umbilical ligament, extending from the umbilicus to the bladder on the deep surface of the anterior abdominal wall [27]. Anatomically, a persistent sciatic artery originates from or is a continuation of the internal iliac artery (2,9,11,12,15,20,24, 32-41], while embryologically the sciatic artery originates from the umbilical artery [1] which in turn becomes the inferior gluteal artery anatomically. The sciatic artery could also become the superior or inferior gluteal artery [42]; these arteries are therefore the proximal segments of the sciatic artery during regression. However, coexistence of all three arteries (sciatic, superior and inferior gluteal) has been reported [37] (Fig 1).

Therefore, this current study focuses on the variability superior and inferior gluteal arteries with coexistence of sciatic and axial artery or both.

Method

Over a period of 4 years 342 hemipelves from 171 cadavers (92 male, 79 female) were dissected to study the sciatic artery origin and its branches. The origin and branches of the sciatic artery present as photographic record was taken of each specimen. The current study was conducted in the University of Dundee in Scotland. This study has done under regulation and rule of Scotland research which has been approved from the Centre for Anatomy and Human Identification. Also, the photo permission has been taken under ethical approval of the Centre for Anatomy and Human Identification.

Once the anterior abdominal wall, foregut and hindgut had been dissected by undergraduates as part of their studies, a transverse section through or above L4 or L5 was made followed by sagittal sectioning of the pelvis: the peritoneum was then carefully removed. In females removal of the vesicouterine pouch revealed the deep structures. Clarification of the broad ligament, as well as identification of the uterine tube and the ovary with its ligament was undertaken: these structures were released and reflected from the lateral pelvic wall. In males, the vas deferens was removed or reflected superoanteriorly. At the level of the sacral promontory, the sigmoid colon was sectioned from the rectum at the rectosigmoidal junction: Waldeyer's fascia was incised and the rectum released from the pelvic wall. After reflection of the pelvic viscera, the pelvic fascia was divided and removed from the pelvic wall. Subsequent to removal of the endopelvic fascia, the iliac system (venous and arterial) was exposed: the veins were carefully removed up to the level of formation of the common iliac vein.

Following dissection of the pelvic region, the gluteal region is the second area in which to trace the sciatic nerve and the arteries arising from the internal iliac artery passing through the greater sciatic foramen either above or below piriformis. Prior to dissection, the sacrum, ischial tuberosity and greater trochanter of the femur were used as landmarks through palpation. The incision followed these landmarks to remove the skin and subcutaneous tissue. An incision was made over gluteus maximus following an imaginary line starting from the sacrum and curving over the terminal part of the outer lip of the iliac crest. To complete the gluteus maximus dissection, the sacrotuberous ligament was identified by palpation to avoid dissection of the ligament. Gluteus maximus was reflected with the inferior gluteal artery and superficial branch of the superior gluteal artery sectioned. As soon as gluteus maximus was bisected and reflected, piriformis, superior and inferior gemelli, and obturator internus tendon were exposed. Piriformis was identified and the sciatic nerve course traced in relation to the muscle.

Piriformis is situated inside and outside the pelvis and is a landmark for many structures passing above and below it. To determine the variability of sciatic artery course in relation to the upper and lower edge of piriformis was taken. The ischial spine and sacrospinous ligament were identified to find the internal pudendal artery. The internal pudendal artery and inferior gluteal artery branches were followed. The internal pudendal artery usually give no branches in the gluteal region, except in a few cases it may give sciatic, muscular and articular branches. Careful observation was made of these branches because the sciatic artery may arise from the internal pudendal artery. The inferior gluteal artery usually gives three branches: coccygeal, articular and ischiadic branches. The inferior gluteal artery arises lateral to the internal pudendal artery and medial to the sciatic nerve. An observation of the sciatic and articular branches arising from the inferior gluteal artery during its course in relation to sciatic nerve was recorded. A large prominent sciatic branch with a large lumen and prolonged course is classified as a sciatic artery. The superior gluteal artery may give a sciatic artery crossing the dorsal aspect of piriformis exiting above it. The sciatic artery has been traced from pelvis to gluteal region as well as the terminal course. The terminal course has been divided into complete and in complete according to Bower et al. [2].

Result

This study assesses the variability of sciatic arteries arising from the internal iliac artery directly and indirectly which supplies the lower limb. It also reviews the presence of the cardinal features of the sciatic artery including its classical features. This present study includes 171 cadavers (342 hemipelves). In present study, sciatic arteries were observed to arise from a number of different arteries in 68 specimens: anterior trunk of the internal iliac (12 specimen); internal pudendal artery (1 specimen); posterior trunk of the internal iliac artery (44 specimens); anterior and posterior trunks as a double artery (4 specimens); superior gluteal artery (7 specimens) (Table 1). In addition, the sciatic arteries were observed to give the superior and inferior gluteal arteries (12 and 9 specimens respectively).

Arterial Development in the Lower Limb

At four weeks gestational age the embryo consists of 42 somites. When the limb buds appear the capillary plexuses arising from the somites pass into them forming the major vascular trunks and their branches. These blood vessels either develop further or regress depending on blood flow requirements: if blood flow decreases or is diverted to regions/areas away from the primitive vessels, the vessel regresses. As the embryo grows in size the requirements of the lower limb buds increases, obtaining their initial blood supply from capillary plexuses [4,43,44], which arise from the umbilical artery, in turn arising from the ventral paired branches of the dorsal aorta located at the 4th branch level [28].

At the 6mm length stage (29 days gestational age) the capillary plexuses develop into the primitive axial artery facilitating growth of the lower limb buds [4, 43,44] up to the 9mm length stage [35,45,46] via a process of consolidation within the plexus [43; 47, 48]. This vessel is the primary axial artery of the lower limb bud [43].

At the 8.5mm length stage (32 days gestational age) the external iliac artery arises, becoming the femoral artery as it runs on the anterior aspect of the future thigh [43].The external iliac artery arises from the lateral side of the umbilical artery proximal to the origin of the sciatic artery and divides into proximal and distal parts, which become the common and internal iliac arteries and their branches, respectively [43]. At the 9mm length stage (33 days gestational age) the primitive sciatic artery passes along the dorsal aspect of the skeletal mesenchyme towards the sole of the foot [4]. By the 35mm length stage (35 days gestational age) the external iliac artery becomes continuous with the common and superficial femoral arteries [4,35,45] (Fig 2).

Following regression of the middle part of the axial artery (beyond the 10mm length stage - approximately 34 days gestational age), an anastomosis develops between the dorsal sciatic and ventral femoral arteries: this is the precursor of the deep femoral artery (profunda femoris) [49]. The middle part of the femoral artery persists as a large trunk in the ventrally lying rete femorale. The profunda femoris therefore has an embryological origin from the rete femorale [50], explaining its variation in origin, branches and course (Fig 3).

At the 14mm length stage (37 days gestational age) the primitive sciatic artery is fully developed and has established anastomoses with the femoral artery. The arterial supply to the lower limb is therefore from the external iliac/femoral artery (anterior system), and the sciatic artery (posterior system) [43]. Subsequently, an accelerated development of the femoral system occurs as the primitive sciatic artery completely regresses [4,33,51]. Conversely, failure of development of the femoral artery or regression of the primitive sciatic artery results in a persistent sciatic artery [33,45] and hypoplasia of the external iliac and femoral arteries [52] (Fig 2 and 3). At the 22mm length stage, following its regression around the third month of development, the proximal part of the sciatic artery becomes the inferior gluteal artery [7,18, 40,43] and then regresses becoming the artery of the sciatic nerve [36] observed in 39% of specimens by Georgakis and Soames [53] the middle part regresses [54]. Anatomically, the sciatic artery is a prolongation of the inferior gluteal artery leaving the pelvis through the greater sciatic foramen with the sciatic nerve [33,55,56,57]. Persistent anomalous branches may also arise from the superior gluteal artery when the inferior gluteal artery is absent. It has been suggested that the superior and inferior gluteal arteries persist following axial artery regression [4,44,51].

At 41 days gestational age the sciatic artery splits into proximal and distal parts which separate: the proximal part develops into the inferior gluteal artery [43] and the distal into the popliteal artery [33,43;59]. The popliteal artery then anastomoses with the superficial femoral artery becoming a continuation of it at the adductor canal (50;54). Developmental anomalies during these embryological stages result in variations in the arterial supply of the lower limb [31,49,60].

Axial Artery: a new perspective

The major arterial supply of the lower limb during the first trimester is the primitive axial artery [4,29,30]. Embryologically, it arises from the umbilical artery from the dorsal aorta at the 4th branch level [28]: anatomically, it is a direct continuation of the internal iliac artery leaving the pelvis through the greater sciatic foramen below piriformis with the sciatic nerve. With development of the iliofemoral system from the external iliac artery, the axial artery regresses. The primitive external iliac artery begins to develop at the same time as the primitive axial artery divides into three parts; proximal (upper), middle and distal (lower) which become the internal iliac, profunda femoris and popliteal arteries, respectively. The internal iliac artery lies dorsal to the umbilical artery and ventral to the external iliac artery: it then divides into two trunks, anterior and posterior. Anatomically, persistent sciatic and axial arteries may arise from either trunk directly or indirectly via one of its branches, explaining its diverse origin and presentation as either the superior or inferior gluteal artery. A persistent sciatic artery is therefore a remnant of the proximal part of the primitive axial artery, whereas the direct continuation of the internal iliac is a persistent axial artery. Consequently, sciatic artery is the terminology used to describe either a persistent sciatic or persistent axial artery which, embryologically, is the primitive sciatic or axial artery.

With further development the proximal part of the umbilical artery, which is proximal and dorsal to the origin of the external and internal iliac arteries, is part of the common iliac artery. Anatomically the common iliac artery bifurcates into external and internal iliac branches, which develop from the upper and lower segments of the primitive axial artery, respectively. As the lower limbs start to rotate medially, the middle part of the primitive axial artery moves from dorsal to ventral. With further rotation branches from the middle part extend in length becoming the perforating arteries (Fig 4 and 5). As the primitive external iliac artery lengthens distal to the inguinal ligament it becomes the primitive femoral artery and is joined by the middle part of the primitive axial artery, dividing the primitive femoral artery into proximal (upper) and distal (lower) parts. The proximal part of the primitive axial artery is the primitive common femoral artery, the distal part becomes the primitive superficial femoral artery, while the middle part becomes the deep femoral (profunda femoris) artery. In the adult this arrangement is seen as the common femoral artery dividing into superficial and deep femoral branches. At the adductor canal, the primitive superficial femoral artery joins the distal part of the primitive axial artery to become the popliteal artery (Fig 6).

This new perspective depends on three principle events. Firstly, whether the primitive axial artery divides or not, which presents as incomplete or complete forms: the presence/absence of the profunda femoris is evidence of division/non-division of the axial artery. Secondly, medial rotation of the primitive axial artery as the lower limb rotates medially: this explains the appearance or not of the profunda femoris, as well as its fusion or separation at different sites (Fig 6). Thirdly, the vascular demand of structures within the pelvis and lower limb, which in turn determines the presence/ absence of a vascular supply, includes the course of the vessels. The fate of the axial artery is principally determined by the development of the iliofemoral system. Failure of any of these events and/or changes in their timing will give rise to variations in the arterial organisation of the pelvis and lower limb, leading to differences in the systemic arterial supply of these two regions (Fig 5 and 6).

Discussion

In comparative anatomy study, the sciatic or ischiadic artery is a principle artery supplying the thigh in different species such as amphibian, reptilia and birds. It was known as saphena artery and found to have different vascular development stages in different species [61] while Zuckerkandl [62] described the saphena artery in all mammalian in detail. Manners-Smith [63] who considered that in primates the main artery is not the sciatic but the saphena. Later, De Vriese [64] stated that the saphena artery is a chief artery of the lower limb. Moreover, the ischiadica artery is a direct branch of the aorta giving the umbilical artery (from the proximal part) in mammalian. This debate has been between scientist from 1890 till 1912 [61-64] therefore Evans [65] stated the origin of this artery is still ambiguous in human.

As noted earlier persistent sciatic or axial artery is a rare vascular anomaly resulting from a lack of regression of the embryonic dorsal axial (ischiatic) artery. Moreover, in the later stages of regression, particularly if the dorsal axial artery does not fully regress, it is known as the inferior gluteal artery [7,18,40,43] or the commitans sciatic artery [36]. In the absence of an inferior gluteal artery an equivalent branch may arise from the superior gluteal artery [66] (Fig 7). Others consider that the superior and inferior gluteal arteries are the remaining parts of the axial artery following its regression [4,44,51,58], suggesting that the regression theory regarding persistence of the sciatic artery cannot be correct if all three arteries are present as a persistent axial or sciatic artery are considered to be a prolongation of the superior or inferior gluteal arteries (2, 3, 4, 6, 7, 8, 9, 10, 59, 11; 12, 13, 14, 15, 17,18, 19; 20,21, 22-26). There is, therefore a conflict between these opinions, reinforced by the observation of the presence of superior and inferior gluteal and persistent sciatic arteries [37], which was also observed in the present study: consequently the regression hypothesis needs to be revised (Fig 1). The proposal put forward is on the basis of observations in the present study which considers that a persistent sciatic artery is not an axial artery, but is the coexistence of a remnant of the embryological axial artery. Therefore, the proximal part of the axial artery is, embryologically, neither the superior nor the inferior gluteal artery.

From Senior [43] studies considered the external iliac artery to arise from the lateral side of the umbilical artery at the 8.5mm length stage, dividing it into proximal and distal parts, which become the common iliac and internal iliac arteries and their branches, respectively. Several authors have proposed that anatomically the persistent axial artery is a direct continuation or branch of the internal iliac artery [2, 4,9,11,12,13,14,15,20,24,32,33,36,37,38,39,40]. However, embryologically, the internal iliac artery develops from the proximal part of the axial artery, as well as the axial artery being anatomically a continuation of the internal iliac artery. Comparison of the diameters of the internal and external iliac arteries has shown the internal iliac artery to be the larger [67], suggesting that it may develop earlier than the external: this is contrary to accepted embryological theory. One possible explanation for the larger diameter of the internal iliac artery is that it was the proximal part of the axial artery and therefore is responsible for supplying the embryonic lower limb rather than the pelvis.

It has been suggested that the common iliac artery does not bifurcate when it compensates for the internal iliac artery, but that in addition to the external iliac artery it gives branches to the pelvis: this is the case particularly in congenital absence of the internal iliac artery with persistence of the sciatic artery [68]. The common iliac continues as the inferior gluteal artery, while the external iliac gives pelvic branches such as the internal pudendal, umbilical, uterine, inferior vesical and obturator arteries [68]. Absence of the internal iliac artery is due to regression of the lower segment of the proximal part of the axial artery, i.e. that part below the umbilical artery, with the non-dividing and non-medially rotating axial artery continuing as a persistent axial artery. The presence of inferior gluteal and persistent axial arteries is not consistent with the current embryological theory. Tamisier et al. [69] reported a case in which the external iliac artery was absent with the common iliac artery continuing as the internal iliac artery. More recently, Sabanciogullari et al. [70] observed a case of the sciatic artery being the direct continuation of the common iliac artery. This cannot be explained by the current embryological theory as the sciatic artery is a direct continuation of the inferior gluteal artery. However, in the proposal put forward in this paper the proximal part of the axial artery becomes the iliac system (common, internal and external iliac arteries): as the axial artery arises its proximal part divides into upper and lower segments which become the common and internal iliac arteries, respectively.

One area of agreement between the current embryological theory and the present proposal is with respect to hyopoplastic development of the iliofemoral system leading to a persistent axial artery (Fig 2 and 3). The proposal considers that the axial artery may develop, irrespective of whether the iliofemoral system develops, from either the internal or external iliac artery. The presence of both internal iliac and sciatic (axial) arteries is not however consistent with this proposal, which is based on three events: division of the axial artery, medial rotation of the lower limb, and vascular demand. If the axial artery does not divide or medially rotate the result is congenital absence of the profunda femoris. In this case, the internal iliac artery is formed from the proximal part of the primitive axial artery due to the vascular demand of structures within the pelvis.

Similarly, structures in the anterior compartment of the thigh require a vascular supply from the internal iliac artery in congenital absence of the external iliac artery irrespective of non-division and non-rotation of the middle part (profunda femoris) of the primitive axial artery, which usually supplies this compartment via its perforating branches. A case of congenital absence of the external iliac artery with proper development of the internal iliac artery and no evidence of an axial artery or profunda femoris supports the proposal [71]. In this case, the axial artery divided giving a proximal part, which became the internal iliac artery; however medial rotation was not completed resulting in the middle part not reaching the undeveloped femoral artery. As a result the perforating branches came to lie between the anterior and posterior compartments without anastomosing (Fig 4). This scenario presents as collateral branches gaining blood from other collateral branches (e.g. coeliac, superior mesenteric, inferior mesenteric, renal, common iliac and internal iliac arteries) and ending as the popliteal artery. Individuals with this scenario are likely to have delayed lower limb growth due to delayed vascular demand in addition to the non-division and medial rotation of the axial artery.

Regression of the femoral and axial systems does not support the current embryological theory, but does support the new proposal. In cases of congenital absence of the external iliac artery the internal iliac artery provides the blood supply to the lower limb as well as the profunda femoris [72]. According to Shortell et al. [72] this vascular anomaly can be explained as follows: the infrarenal aorta gives the internal iliac and sciatic arteries running ventral and dorsal in the lower limb respectively. While the femoral artery is formed from the rete femoris, the sciatic artery provides the main supply for the lower limb as well as the sciatic nerve (Fig 2, 3 and 4). However, according to the new proposal the explanation is as follows: the axial artery divides and medially rotates, with the proximal part becoming the internal iliac artery continuing as the femoral artery when the external iliac artery is absent; the middle part rotates medially and joins the femoral artery to become the deep femoral artery (profunda femoris); while the third part continues as the superficial femoral artery to become the popliteal artery distal to the adductor hiatus (Fig 5 and 6).

In the classification of persistent sciatic artery by Pillet et al. [73] Type I has a complete axial artery originating from the internal iliac artery which terminates in the popliteal artery due to absence of the profunda femoris.

This congenital absence can be explained by non-division and medial rotation of the axial artery. Sekiya et al. [74] reported several arterial variations throughout the body; however with respect to this study in a case of persistent sciatic artery they described the popliteal artery as a continuation of the deep femoral artery (profunda femoris). The current embryological theory cannot explain this anatomical anomaly, whereas the new proposal can. On the basis of the three events outlined earlier with respect to the primitive sciatic artery, the proximal part separates from the middle part and continues as the iliac system as previously described. If the proximal part fails to regress completely the sciatic artery persists as the lower segment of the proximal part. The upper segment of the proximal part gives rise to the primitive external iliac artery, which then continues as the primitive femoral artery. At the same time the middle and lower parts of the primitive sciatic artery undergo medial rotation. The middle part joins the femoral system dividing it into two parts, the common femoral and superficial femoral arteries, continuing itself as the deep femoral artery with the lower part becoming the profunda femoris. An alternative scenario is that the middle part of the primitive sciatic artery separates from the lower part and rotates medially to join the primitive femoral system. Because of a delay in the development of the primitive femoral system and the vascular demand of the lower extremity, as well as the middle part being more mature than the primitive femoral system, this leads to the middle part joining with the lower part, resulting once again in the deep femoral artery continuing as the popliteal artery. However, a rare case of double profunda femoris does not appear to support the new proposal. The proximal profunda femoris arose from the common femoral artery, together with the circumflex femoral arteries, descending for a short distance and then disappearing, whereas the more distal profunda femoris arose from the common femoral artery and gave perforating branches to the anterior compartment [75]. By definition the perforating arteries are named because they perforate adductors brevis and magnus. The perforating arteries leave the anterior compartment by piercing the transverse intermuscular septum to gain access to the posterior compartment [27,76] as the superior (1st), middle (2nd) and inferior (3rd) perforating arteries [77]. These residual muscular branches arise from a common trunk of the superficial femoral artery and not a distal profunda femoris, hence the confusion of a double profunda femoris. In the present study, these perforating arteries gave branches to the sciatic nerve in entire specimens (Fig 4), explaining why profunda femoris embolism results in sciatic nerve palsy [78,79]. In the new proposal these perforating arteries are remnant branches of the middle part of the axial artery, which elongates as this part rotates. The nutrient artery, referred to as the 4th perforating artery, is a terminal branch of the profunda femoris [59] confirming that the middle part has no distal continuation when there is proper development of the femoral system in the new proposal. Non-development of the perforating arteries due to non-division of the middle part of the axial artery without medial rotation leads to complete development of the sciatic (axial) artery without supplying the anterior compartment of the thigh [37].

An inferior gluteal artery and profunda femoris, as well as a persistent sciatic artery, have been reported by Paraskevas et al. [21]: this appears to be contrary to both the current embryological theory and new proposal (Fig 7). A persistent sciatic artery together with an inferior gluteal artery does not support the embryological regression theory [2,3, 4, 5 6,7; 8, 9, 10,11,33, 12,13,14,15,17,18,19,19,20,21,22-26,48,51,58]. However, the new proposal explains that both arteries are remnant branches of the proximal and middle parts of the axial artery. In the study by Paraskevas et al. [21] a persistent sciatic artery presented with the profunda femoris, which then continued as the popliteal artery. The current embryological theory cannot explain this anomaly. However, in the new proposal this can be explained in terms of the three events associated with the axial artery: due to vascular demand it disappears when the persistent sciatic artery appears, but does so from the anterior not the usual posterior trunk, indicating axis orientation of the proximal part of the axial artery and a residual branch from it rather than the axial artery itself. When a supplementary supply to the limb is required this remnant branch continues as the popliteal artery instead of the femoral artery, thereby gaining a selective connection. It can be argued that the distal part of the axial artery and its remnant are more mature than the femoral system.

In the new proposal it is possible to understand the origin and behaviour of the sciatic artery, i.e. its persistence or absence, during development of the iliofemoral artery, from either the internal or external iliac arteries, during normal development as well as in hypoplasia and aplasia.

The profunda femoris has been observed to arise between 25 and 51mm [80] in 68% of individuals, and from 20 to 60mm [81,82,83,84] below the inguinal ligament, or from 0 to 80mm below the midinguinal point with a median distance of 44mm ([85] or 35mm [86]. However, the profunda femoris has been observed to arise from the femoral artery less than 10mm distal to the inguinal ligament [87]. The origin of the profunda femoris has also been classified in relation to the femoral triangle, being in the 1st quarter in 59.5%, the 2nd quarter in 27.5%, the 3rd quarter in 11% and the 4th quarter in 2% [88]. These observations suggest different sites of union of the primitive profunda femoris with the primitive femoral system, which was the middle part of the axial artery in the embryo. Occasionally the profunda femoris arises from the external iliac rather than the femoral artery [89]. This can be explained by a delay of the primitive femoral system from the primitive external iliac system, as well as the vascular demand of the lower limb in addition to medial rotation of the middle part, leading to the middle part joining the primitive external iliac artery to become the profunda femoris.

The profunda femoris has been reported to arise from the superficial femoral artery at several locations: most commonly laterally, dorsally or dorsolaterally and less commonly medially and dorsomedially [49,80,85,86,89,90-95]. This variability is probably due to the degree of medial rotation of the middle part of the axial artery around the femoral axis (Fig 8). At the 11-13 mm embryo length stage several events occur. Firstly, the foot disc starts to develop being oriented in a transverse plane with the plantar surface ventral: the disc then rotates medially to lie in the median sagittal plane. Secondly, the initial phase of skeletogenesis starts, referred to as mesenchymal condensation[96]. Rotation of the axial artery or its divisions begins and continues beyond this stage.

Development and rotation of the lower limb occurs in different organising periods. Any fault or delay in this serial arrangement can lead to a congenital anomaly, such as clubfoot, with a greater expectation of vascular anomalies. The different orientations of the origin of the profunda femoris support the new proposal.

There are many reports of the profunda femoris arising from the medial side of the common femoral artery and then passing from medial to lateral superficial to the femoral vein [80,80,89,91]. In these cases the process has occurred earlier than venous system development, which itself arises from the small plexus medial to the femoral artery. Tanyeli et al.[97] have reported a profunda femoris arising from the anterior aspect of the femoral artery: similar reasoning can be applied in that incomplete medial rotation has occurred.

The new proposal regarding arterial development of the lower limb and the new classification system of persistent sciatic and axial arteries allows a full and complete understanding of the development of the lower limb vasculature and can account for all anomalous cases reported in the literature. In the new classification, the organisation of the sciatic artery is either prominent or a remnant. In addition, the iliofemoral system can arise from either the internal or external iliac artery. Based on current study variations, these anatomical variants prove Hochstetter [61] and De Vriese [64] in which ischiadica artery is a direct branch of the aorta giving the umbilical artery (from the proximal part) in mammalian.

Coexistence of axial artery is associated with variability of internal iliac artery branches modifying the internal iliac artery classification which has clinical significance in medical fields [98]. With a variability of the internal iliac artery branches in origin and course, there is a variability of tissue vascular supply such as sciatic nerve. Understanding the variability of the internal iliac artery branches will avoid iatrogenic sciatic neuropathy [99]. The risk of sciatic neuropathy increases as the sciatic artery provides lateral sacral and iliolumbar arteries [98-100] becoming a chief supply of sciatic nerve.

Therefore, radiologists, orthopaedic surgeons, obstetricians, gynaecologists and vascular surgeons must be aware of the variability in vasculature and vascular anomalies in the lower limb, as well as their coexistence with a persistent sciatic and/or axial artery. An awareness of these variations should reduce postsurgical complications.

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Figure legend

Figure 1: The persistent sciatic artery (PSA) is a continuation of the posterior trunk of the internal iliac artery (PT IIA) which passes between the lumbosacral trunk and S1 root. Inside the pelvic cavity, the persistent sciatic artery (PSA) gives three lateral sacral arteries (LSA) and obturator artery during intrapelvic course. Then, it exits from the pelvic cavity through the greater sciatic foramen below the inferior border of piriformis. The anterior trunk branches into umbilical (UMA) and superior vesical arteries (SVA), and gluteopudendal trunk (GPT). This trunk divides into inferior gluteal (IGA) and internal pudendal arteries (IPA). Presentation of the three arteries (Coexistence of the superior and inferior gluteal and persisitent sciatic arteries) is counter to the regression theory of axial artery embryology.

Figure 2: The blood supply to the lower extremity is initially provided by the sciatic artery system, which is a branch from the internal iliac (A), and continues as the popliteal artery (B). By the sixth week of gestation, the external iliac/iliofemoral system begins to develop, joining the sciatic system at the popliteal artery (B). The sciatic artery system normally regresses, persisting proximally as the superior and inferior gluteal arteries and distally as the popliteal artery and its bifurcations (C). (Adapted from Sidway AN. Embryology of the vascular system. In: Rutherford RB, editor. Vascular surgery. 6th ed. Philadelphia: Elsevier; 2005. p. 53-63).

Figure 3: Development of the arteries of the lower limb. 1.Rete Femorale, 2. Rete Pelvicum, 3.Sciatic Artery, 4.Femoral Artery, 5.Deep Femoral Artery, 6.Medial Circumflex Femoral artery, 7. Lateral Circumflex Femoral Artery, 8.Femoral Vein. (Redraw based on descriptions of Sanudo et al [101] and adapted from Sahin et al 102).

Figure 4: The perforating arteries penetrate the Transverse intermuscular septum to supply the posterior compartment as well as the anterior compartment of the thigh. With medial rotation these perforating arteries extend in length as they travel from dorsal to ventral compartment attaching the middle division of the axial artery. The sciatic nerve obtained blood supply from perforating via Arteria Ischiadic Perforante Profunda Femoris.

Figure 5: The persistent sciatic or axial artery can take several origins inside the pelvis. The internal iliac artery develops from the lower segment of the primitive axial artery, whereas the external iliac develops from the upper segment. Therefore, the common iliac artery develops dorsal to the external iliac origin, also as from upper segment (a). The lower segment of the proximal part of the primitive axial artery gives rise to the posterior trunk of the internal iliac artery as the anterior trunk starts to develop (b). The persistent sciatic artery (yellow) may arise from the anterior trunk directly (c) or indirectly (d). The persistent axial artery (yellow) continues as the posterior trunk (e) or may arise from the posterior trunk of the internal iliac artery directly (f) or indirectly (g) depending on the direction of blood flow. Occasionally, the internal iliac artery bifurcates into persistent axial and superior gluteal arteries (h).

Figure 6: Sciatic artery course (a) sciatic artery passes down the lower limb towards the sole of the foot; (b, c) the sciatic artery divides into three parts (superior, middle and inferior) which become the common iliac, deep femoral and popliteal respectively; (d) the middle part begins to rotate medially as the external iliac artery appears and grows; (e) the middle part begins to give perforating branches and joins the femoral artery, which is a continuation of the external iliac artery; (f) the middle part becomes the profunda femoris and divides the femoral artery into the common femoral artery (above) and the superficial femoral artery (below) to continue with the popliteal artery.

Figure 7: A case of congenital absence of the inferior gluteal artery where the persistent sciatic artery (PSA) arises from the superior gluteal artery, being referred to as the 'Glutie Arteria Ischiadic Glutea Superioris'.

Figure 8: Post-division of axial artery, the middle division passes from the dorsal to ventral compartments with medial rotation of the lower limb. The middle division becomes the deep (profunda) femoral artery joining the femoral artery and dividing it into two parts. At the site of union the upper (proximal) part becomes the common femoral artery, whereas the lower (distal) part becomes the superficial femoral artery. In this figure the deep femoral artery shows incomplete medial rotation joining a long circumflex femoral trunk giving medial and lateral circumflex femoral arteries at the medial and lateral ends respectively.

Fig 1

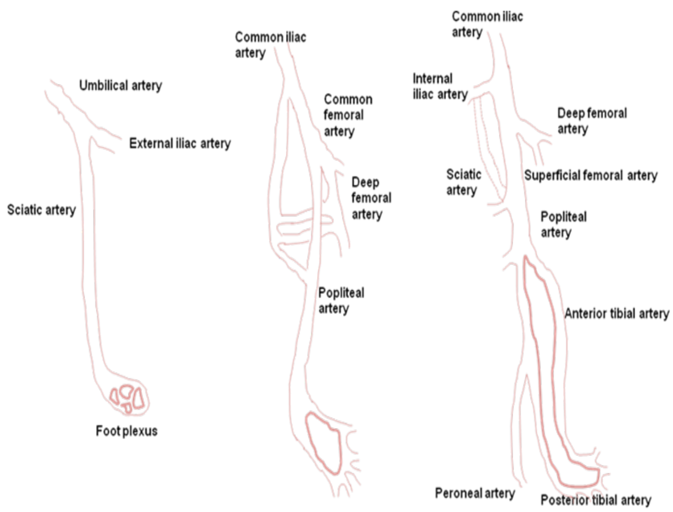

Fig 2

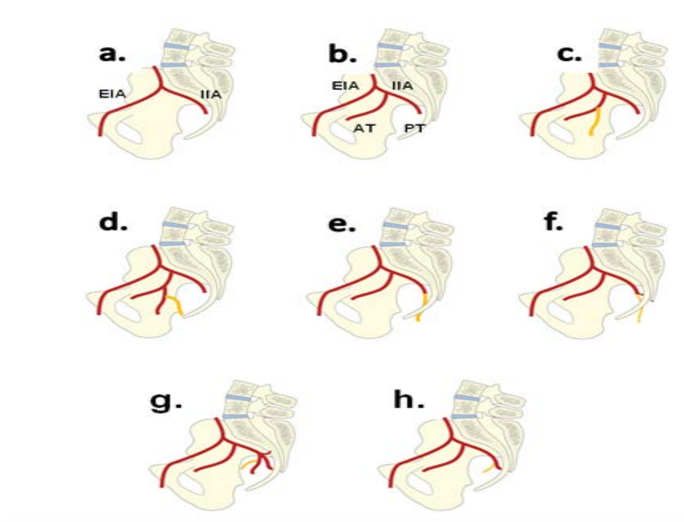

Fig 5

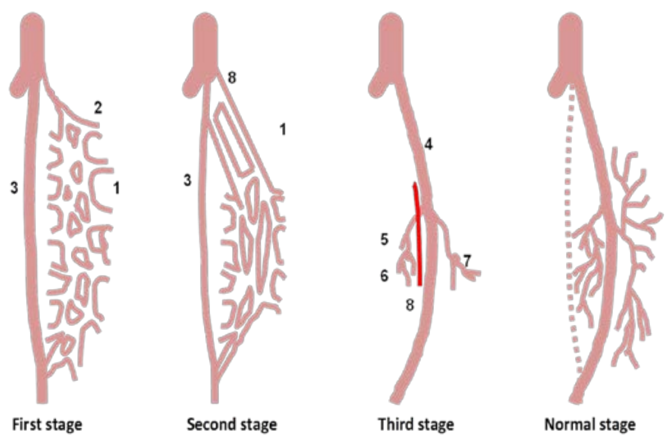

Fig 3

Fig 6

Fig 4

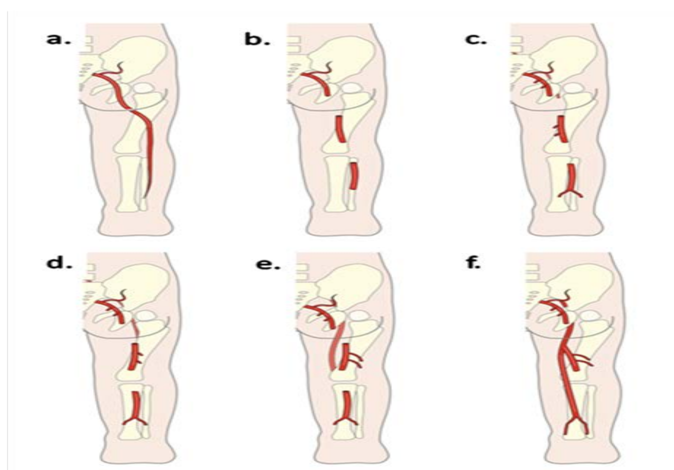

Fig 7

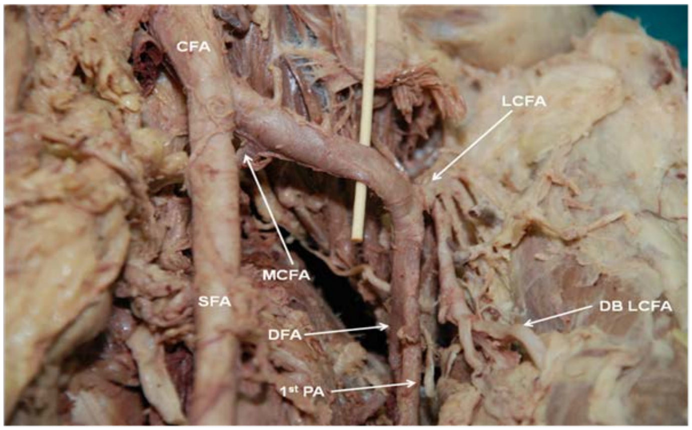

Fig 8

Table 1: Persistent Axial and Sciatic arteries origin and its branches

Origin	Frequency
Anterior trunk (directly)	12
Posterior trunk (directly)	44
Anterior trunk and posterior trunk (directly)	4
Internal pudendal artery	1
Superior gluteal artery	7
Branches	
Superior gluteal artery	12
Inferior gluteal artery	9

The sciatic artery frequently arose from the posterior trunk of the internal iliac artery directly and indirectly. However, it also arose from the anterior trunk directly and indirectly. Observations based on 171 cadavers (342 specimens).