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Descending Branch of the Lateral Circumflex Femoral Artery - Arterial Genicular Anastomoses

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DESCENDING BRANCH OF THE LATERAL CIRCUMFLEX FEMORAL ARTERY: ARTERIAL GENICULAR ANASTOMOSES

(spine title: Arterial genicular anastomosis: descending branch lateral circumflex femoral)

by

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ABSTRACT

Genicular collateral arterial circulation is required for perfusion of the lower leg should the superficial femoral artery (SFA) become obstructed by trauma or disease. When describing the anatomy, textbooks only provide a schematic representation of the genicular collateral circulation and suggest that the descending branch of the lateral circumflex artery (DBLCFA) plays a critical role. The DBLCFA may be removed for bypass and reconstructive surgeries; therefore, a sound anatomical description of this artery is essential. This study combines dissection with 3D reconstruction to describe the anatomy of the DBLCFA and to provide a morphological description of its involvement in the genicular anastomosis. Arterial anatomy of ten cadaveric lower limbs was dissected from the inguinal ligament to the level of the tibial tubercle. Furthermore, a 3D model of the anatomy was created using AMIRA and OSIRIX. The origin of the DBLCFA was found to be variable and the artery should be renamed since it does not always originate from the lateral circumflex femoral artery (LCFA). The results showed collateral circulation at the knee is also variable: continuous communicating vessel (1/3); possible communication via capillaries (1/2): no evident communication (1/5). There is anatomical evidence that LDAT contributes to a collateral pathway should the femoropopliteal segment become occluded; its removal is not recommended. LDAT may provide a route for infusion of growth factors or placement of a stent in situations of acute trauma to the SFA that is not bypassable by traditional surgery.

Keywords: genicular, anastomosis, anatomy, arterial, profunda femoris, descending branch lateral circumflex femoral, superior lateral genicular artery

CO-AUTHORSHIP

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Involved in the design of the study

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ALT	Anterolateral thigh
CFA	Common Femoral Artery
DBLCFA	Descending branch lateral circumflex femoral artery
ILGA	Inferior lateral genicular artery
LCFA	Lateral circumflex femoral artery
LDAT	Lateral descending artery of the thigh
MCFA	Medial circumflex femoral artery
PA	Popliteal Artery
PFA	Profunda femoris artery
SFA	Superficial femoral artery
SLGA	Superior lateral genicular artery
SMGA	Superior medial genicular artery

Anastomosis: a cross connection of blood vessels in a disease-free state.

Collateral circulation: development of alternative routes for blood in response to disease.

INTRODUCTION

Clinical Importance of the Profunda Femoris Artery and its Branches

It is well known in the literature that the profunda femoris artery (PFA) sends out anastomotic branches as it passes down the thigh. Because of its ability to form collaterals, revascularizing this artery has shown to be an effective method of treating the ischemic limb. The first such method was described in 1961 by Leeds and Gilfillan (19) and by Martin et al. (22). They illustrated that by utilizing the PFA as an inflow source, blood flow to the lower limb can be improved. Various other studies have supported and amplified this conception (2, 13).

Furthermore, Martin and Crawford Jamieson (21) in 1974 provided results that highlight the adaptive capability of the PFA. They reported that analyzing PFA flow during occlusion of the superficial femoral artery (SFA) may help differentiate a PFA stenosis from a SFA occlusion. They advocate that low flow rates (in the PFA) indicate that a PFA stenosis is significant, but flow rates approaching 160 ml/min indicate the presence of a SFA occlusion. Similarly, Strandness (31) presented data after revascularizing the PFA in the presence of a SFA occlusion. His results showed that in patients with ischemic rest pain, revascularizing the PFA increased resting ankle blood pressure resulting in prompt relief of symptoms. The aforementioned studies indicate that the PFA is capable of forming collaterals which aid in salvaging an ischemic limb.

The PFA is capable of relieving symptoms of an ischemic limb due to another important factor – it is relatively free of atheromatous plaques (18, 20). Some authors have described the PFA as an artery of supply as opposed to an artery of conduction (13, 20). Such authors contend that in atherosclerosis, it is the arteries of conduction (e.g.

femoral, iliac, aorta) that become more affected by atheromas, whereas arteries of supply (e.g. PFA, renal, mesenteric) are usually relatively disease-free, except for the first centimetre of their course. As a result, in instances where the femoropopliteal or the aortoiliac segment is occluded, the PFA serves as a prime inflow source candidate when attempting to bypass a diseased arterial segment. Several studies have supported such a procedure (9, 10, 15, 30). Such studies demonstrate that the PFA is capable of taking over the function of the SFA so successfully that no detectable diminution of pedal pulses is incurred. This is supported by angiographic studies that show once the femoropopliteal segment is occluded, the PFA and its corresponding collaterals enlarge (13, 20) and blood flow is markedly increased (3, 22).

Contrarily, collaterals connecting the PFA to other arteries of the lower limb have the potential to cause harm. Mousa et al. (26) reported a case in which collateral perfusion to a popliteal aneurysm caused it to rupture 11 years post initial treatment. The authors believe that collateral circulation through the superior and inferior genicular arteries was responsible for the continued growth and ultimate rupture of the aneurysm. Therefore, it becomes prudent to understand the anatomy of these collaterals so that, when necessary, blood flow through them may be surgically interrupted.

Although functional studies have been described and cases in which the PFA was utilized as an inflow vessel for bypass have been reported, very little of the anatomy involved in collateral circulation is available in the literature.

History - Anatomy

John Hunter (1728-1793), a renowned Scottish anatomist and surgeon, was one of the earliest scientists to demonstrate the presence of collateral circulation in an animal. Hunter used to conduct experiments on deer in Richmond Park in London, United Kingdom. During the summer, when a buck's antlers were half-grown, Hunter would ligate the external carotid artery, ceasing blood supply to the antlers. Hunter confirmed that the blood supply had been interrupted by noticing that the antlers eventually grew cold and that pulsation of the arterioles that supplied the antlers had stopped. Approximately a week after the vivisection, Hunter returned to Richmond Park to examine the results. He speculated that either the antler was shed or was retained. What he found surprised him: upon laying his hand on the buck's antler he found that the warmth had returned and that the arterioles to the antlers resumed their pulsation. His first inference was that the ligature placed upon the external carotid artery had failed.

To verify his supposition, he sacrificed the buck and injected the arterial system. Upon doing so, he observed that the external carotid artery had indeed been tied but that small branches emanating from the proximal aspect of the ligature had enlarged. He also found that some of these enlarged branches had anastomosed with branches coming off the external carotid artery distal to the site of ligation. After carefully pondering over his results, Hunter arrived at the conception that "capillaries can enlarge according to a stimulus of necessity", and arrived at a relation between his new idea and treatment of aneurisms (1).

At Hunter's time there were no anaesthetics; the only operation for treating aneurisms in the lower limb was the gruellingly painful one of tying the blood-vessels above and below the aneurism followed by amputation. Even more gruelling were the odds of surviving such an operation – a mere 5 percent. Being cognizant of this, Hunter approached a patient of his suffering from an enormous popliteal aneurism. Hunter proposed: “Now, my good man, you know how few of your brother coachmen have left the hospital alive after the best we have been able to do for them; but, if you will consent to let me, instead of cutting out your tumour or cutting off your leg, perform a much smaller and less painful operation, I think you may have a better chance of being cured than by old methods”.

Hunter’s patient replied: “Oh! God bless you sir, do whatever you think right in my case. I am weary of my life”. Hunter’s reasoning behind his proposed operation was that by ligating the femoral artery, the aneurism will significantly decrease in size due to the stoppage of blood flow. The leg, like the deer’s antlers, will first turn cold but then the natural warmth will return to it as new collaterals sprout and anastomose with existing blood vessels. Indeed, the aneurism shrank to a very small size and the patient walked out with all four of his limbs. *The aforementioned account of John Hunter`s operation is based upon William Clift, from his predecessor William Ball, who assisted John Hunter in his work (1).*

A detailed account of the mechanism employed during Hunter’s ligation of the femoral artery was given by John Hatch Power in 1862 (27): “Mr. Hunter was the first who tied the femoral artery for popliteal aneurism. This operation was performed in the year 1785. His first incision was made through the integuments of the anterior and inner part of the thigh, a little below its middle, so as to cross somewhat the internal margin of the Sartorius muscle: the muscle being turned outwards, the fascia covering the artery was exposed and divided, so as to bring the femoral vessels lying within the Hunterian Canal into view. The artery having been disengaged from its connections, a double ligature was passed under it, and then separated, so as to form two distinct ligatures, with a portion of the vessel lying between them: two additional ligatures were applied at certain distances from the two former, making four in all."

After fifteen days, some of the ligatures came off. The patient left the hospital with some open abscesses but the patient eventually perfectly recovered.

Little did Hunter know that anastomotic channels in the lower limb of man have always been present; the lower limb does not need new collaterals to sprout, but, if necessary, blood can reroute from the main channel into an already present, alternate path. It was actually one of Hunter's students, Sir Astley Cooper, who first described that upon ligating the femoral artery "the arteria profunda formed the new channel for the blood. The first artery sent off passed down close to the back of the thigh bone, and entered the two superior articular branches of the popliteal artery. The second new large vessel arising from the profunda at the same part with the former, passed down by the inner side of the Biceps muscle, to an artery of the popliteal which was distributed to the Gastrocnemius muscle; whilst a third artery dividing into several branches passed down with the sciatic nerve behind the knee joint, and some of its branches united themselves with arteries passing to the Gastrocnemii, and, lastly, with the origin of the anterior and posterior tibial arteries" (7).

One of the earliest works to provide accurate depiction of human anatomy was the work of Jones Quain. His work is, to our knowledge, was the first to provide an accurate anatomical delineation of the arteries of the lower limb with remarks on collateral circulation.

Jones Quain (1796-1865) was an anatomist born in Ireland who taught anatomy and physiology at the University of London. He published his book, *Human Anatomy*, in 1849. In his text, Quain intricately described the arteries of the lower limb with reference to collateral circulation. Remarkably, Quain was already aware that the origin of the PFA may sometimes deviate from its normal branching pattern. He noted that the PFA occasionally arises from the medial side of the femoral artery (as opposed to the lateral) and that it may branch as low as 4 inches below the inguinal ligament. He described the PFA as the "great nutrient artery of the muscles of the thigh". It first inclines outwards anterior to iliacus then winds laterally and downwards posterior to adductor longus before veering towards linea aspera. It lies successively in front of iliacus and pectineus and then on adductor brevis and adductor magnus (28).

Quain explained that the two major branches of PFA are the lateral circumflex femoral artery (LCFA) and the medial circumflex femoral artery (MCFA). The LCFA branches from the lateral side of profunda, travelling a short distance behind Sartorius and Rectus Femoris before branching into three sets. The first set of arteries travel transversely outwards winding behind the greater trochanter and reach the back part of the thigh where they anastomose with branches of the MCFA and the perforating branches. The second set are ascending branches that are directed upwards beneath tensor fascia lata where they communicate with branches of the gluteal arteries. The third set are descending branches, usually three or four in number, that are mostly distributed to the anterior muscles of the thigh but a few can be followed down to the knee where they anastomose with the superior genicular branches of the popliteal and with the descending genicular branch of the femoral. The MCFA arises from the medial aspect of profunda and is directed posteriorly to the medial and posterior compartments of the thigh. After giving off these branches, the PFA becomes significantly diminished in size and passes posteriorly close to linea aspera (28)**.**

Next came the work of John H. Power. His book, *Anatomy of the Arteries of the Human Body with Description Anatomy of the Heart*, nicely brings together the anatomy of major arteries and the surgical operations that were conducted during his time. In it he describes Hunter's famous operation of tying off the femoral artery to treat a popliteal aneurism. His book also makes mention of other surgeries of the femoral artery such as treatment of popliteal aneurism by compression on the femoral artery. He describes the latter operation as "one of the greatest achievements in modern surgery" and that "it accomplishes without danger what Hunter's operation effected with the risk of human life." (27).

Power describes the course of profunda and its branches in the following way: the PFA arises from the posterior and lateral part of the femoral 1-2 inches below Poupart's (inguinal) ligament. It courses obliquely downwards and outwards at first passing over the tendon of iliopsoas before turning medially over vastus medialis where it becomes related closely to the anterior crural nerve. It then descends between adductor longus and magnus before terminating posterior to the tendon of adductor longus. The lateral circumflex branch runs transversely outwards behind Sartorius and Rectus Femoris where it gives off 3 branches. The ascending branch runs upwards and outwards towards the anterior superior iliac spine, where it terminates by connected with branches of the superficial and deep circumflex iliac, gluteal, and iliolumbar arteries. The transverse branch runs outwards and then curves around the posterior surface of the femur. The descending branches run downwards and outwards between vastus intermedius and vastus lateralis. They terminate near the patella where they anastomose with the descending genicular and lateral genicular arteries. Power mentioned that these branches may become enlarged in cases of popliteal aneurisms and they require to be ligated when amputating the thigh.

Power also makes specific mention of the anastomotic circulation around the knee joint. It is described in his book in the following way: the descending branches of the LCFA anastomose with the descending genicular artery and with the superior lateral genicular arteries (SLGA). The descending genicular artery also communicates with the superior medial genicular branch of the popliteal artery. The SLGA also connects with a branch of the inferior lateral genicular artery (ILGA). Finally, a second branch of the ILGA communicates with tibial recurrent branch of the anterior tibial artery.

Five years after Power's book the second edition of Gray's Anatomy was published. In his section on arteries, the author makes mention of the safest procedure to apply a ligature on the femoral artery. He states that applying a ligature within two inches of the origin of the femoral artery (i.e. two inches below the inguinal ligament) is "considered very unsafe". He explains that because of the large branches that connect to the femoral artery at that position (e.g. epigastric, circumflex iliacs) there is an increase risk of bleeding at that site. Furthermore, the PFA usually branches off the femoral artery a little over three inches below the inguinal ligament. It is therefore most favourable to apply the femoral ligature between four and five inches from its point of origin (14).

In order to expose the femoral artery, the author suggests that an incision between two and three inches be made along the course of the vessel. The sartorius muscle must then be exposed and drawn laterally. To expose the femoral artery in the middle of the thigh, the author suggested that the incision should be made along the inner margin of Sartorius (14).

The book also makes mention of collateral circulation in the lower limb in detail. Of chief importance in the collateral pathway are the descending branches of LCFA (DBLCFA). Henry Gray describes these arteries as three or four in number passing deep to rectus femoris and then through the substance of vastus lateralis. These branches reach as far down as the knee where they anastomose with the superior genicular branches of the popliteal artery (14).

It is surprising and quite extraordinary that not much has changed in terms of anatomy since the time of Henry Gray. A comparison between the second edition (14) and the fortieth edition (32) of Gray's Anatomy indicates that the arterial anatomy description of the lower limb is close to identical. Both editions describe the course of the perforating branches of the PFA artery in reference to the adductor brevis muscle: the first perforating branch arises proximal to adductor brevis, second anterior to it and the third distal to the muscle. Also, both editions mention that anastomosis between the DBLCFA and the SLGA from the popliteal artery as well as the communication of the descending genicular artery and the inferior medial genicular branch of the popliteal artery. However, there are connections in the most recent edition not mentioned in the second edition. The first is the anastomosis between the first perforating branch of the PFA with the medial and lateral circumflex femoral arteries. The second is the double chain of anastomoses that the perforating branches form with each other, the first being in the adductor muscle and the second being near linea aspera. Lastly is the anastomosis between the superior muscular branches of the popliteal artery (usually two or three vessels that arise proximally and pass to adductor magnus and the hamstrings) and the termination of the PFA (32).

Variations in Anatomy of Profunda Femoris Artery

Since the PFA is the most important vessel in the lower limb that provides collateral circulation upon occlusion of the femoral artery, it is essential that its variational anatomy be understood. A report by Siddharth (30) et al. in which 100 lower limbs were dissected found that the PFA originated from the common femoral artery (CFA) anywhere from 0-8 cm below the inguinal ligament. The median distance was 4.4 cm and 70% originated between 3-6 cm. The most common origin was found to be posterolateral while an anterior origin was not seen. The origin of the LCFA showed variation: 67% of the time it originated from the PFA, 16% from the CFA, 3% of the limbs showed the ascending branch commencing from the CFA while the descending branch commencing from the PFA, in 5% of the limbs the LCFA and the MCFA originated with the PFA from the CFA and in 4% of the cases the ascending and descending branches emerged separately from the PFA.

Lippert and Pabst (19) came up with a classification system for patterns and frequency of anatomical variations of the PFA and its branches. In the majority of cases (58%) a common arterial trunk supplies the PFA and all of its branches. In 18% of the cases the MCFA is a direct branch of the SFA and in 15% of the cases the LCFA is a direct of the SFA. In 4% of the cases both circumflex arteries originate from the CFA and in 3% a major branch of the LCFA originates directly from the SFA. In 1% of the cases both circumflex arteries have a common trunk originating from the CFA. In less than 1% of the cases there is no MCFA and also in less than 1% the PFA is a branch of the external iliac artery.

Previous classification systems for the variational anatomy of the PFA have proven to be complex and cumbersome; therefore, a report by Vazques and his colleagues was geared towards proposing a simplified classification useful to clinicians (35). In their classification system the group formulated three patterns. In pattern I (79% of the limbs) both circumflex arteries originated from the PFA: in type Ia the MCFA arose proximal to LCFA (53.2%), type Ib the LCFA arose proximal to MCFA (23.4%) and in type Ic both circumflex arteries arose as a common branch from PFA (23.4%). Interestingly, pattern I was most frequent and statistically significant in the female.

In pattern II (20.5% of the limbs) one circumflex artery arose from the PFA while the other arose from the SFA. In type IIa (77.8% of the 20.5%) the MCFA arose from SFA and the LCFA from the PFA while in type IIb (22.2% of the 20.5%) the opposite was true. In both cases the MCFA was more likely to originate proximal to the LCFA.

Finally, in pattern III (0.5%) the LCFA and the MCFA branched from the CFA. In one case (0.23%) the MCFA was shown to arise from the inferior epigastric artery and leaving the pelvis under the inguinal ligament.

There has also been a case report in which the PFA originated from the anterior aspect of the CFA. On the same cadaver of a 72 year-old male the PFA was giving off the inferior epigastric and the external pudendal arteries, the former usually being a branch of the external iliac artery while the latter is usually a branch of the upper part of the femoral artery (34).

History – Vascular Surgery

An exceptional amount of literature indicates that it was Sushruta, a surgeon of ancient India, who was the first to practice ligation of blood vessels to control bleeding (11). Historians and scholars of ancient Indology place his time somewhere between 600-800 BC. It is therefore not surprising that most early attempts at vascular surgery involved the application of ligatures for the treatment of arterial wounds and aneurysms. The great Roman surgeon and philosopher Claudius Galen spent three years as a surgeon to the gladiators; he therefore obtained an insurmountable amount of experience using ligatures to treat traumatic arterial bleeding (11). The very first recorded attempt to ligate an artery for aneurismal treatment dates back to second century AD when the Greek surgeon Antyllus endeavoured unsuccessfully to treat an abdominal aortic aneurysm (16). Centuries later, in 1817, Sir Astley Cooper attempted to ligate the abdominal aorta for the treatment of a ruptured iliac artery aneurysm but his patient succumbed to a fate similar to that of Antyllus' (5).

In 1888, Rudolph Matas audaciously went against the usual treatment of his time for aneurismal disease (arterial ligation) and revamped an old concept introduced by Antyllus: endoaneurysmorrhaphy – treatment of aneurysms by opening its sac and collapsing, folding, and suturing its walls. Matas performed this technique successfully on a brachial artery aneurysm (24) and in 1923 he was the first to ligate successfully the abdominal aorta for aneurismal disease (25).

Treatment of peripheral arterial disease via ligatures began to fall out of favour early in the twentieth century when Alfred Exner in Austria and Alexis Carrel in France separately pioneered the use of venous autografts into the peripheral circulation (11). Carrel and Charles Guthrie demonstrated their model of vein autotransplantion in dogs (6) and in 1912, Carrel was awarded the Nobel prize in Physiology and Medicine.

However, it was a Spanish surgeon by the name of Jose Goyanes who in 1906 was the first to employ a venous autograft in arterial circulation, and one year later it was a German surgeon, Erich Lexer, who first used a reversed great saphenous vein as an interposition graft (11). The great saphenous vein is currently utilized by vascular surgeons around the world to repair and reconstruct diseased arteries.

Venous grafting failed to reach popularity amongst vascular surgeons until 1948 when Jean Kunlin revived this technique in Paris. Kunlin performed a femoropopliteal bypass surgery employing the great saphenous vein as the bypass graft (16). Synthetic grafts began to surface in 1947 when Arthur Voorhees made an impelling observation: a silk suture accidently placed in the ventricle of a dog became incorporated into the endocardium. This observation led him to speculate that a "cloth tube acting as a lattice work of threads might indeed serve as an arterial prosthesis" (11). A paper in 1952 by Arthur Voorhees, Arthur Blakemore and Alfred Jaretzki established the effectiveness of a cloth prosthesis in the aorta of an animal (36). In 1954 the group optimistically set out to provide evidence of efficacy using the vinyon-N cloth tubes to replace the abdominal aorta of human patients. Their results were not favourable as the early synthetic grafts were prone to degeneration as well as lack of incorporation (4).

Fortunately, synthetic grafting was saved by a world-renowned American surgeon, Micheal Debakey, who in 1957 introduced the knitted Dacron graft prosthesis (8). Modifications of the knitted Dacron graft were later provided by various surgeons, and are currently employed around the world to repair and/or reconstruct arteries.

Advents in vascular surgery have only begun to progress over the last century. The speed at which this nubile field is advancing offers a great sense of comfort for the management of vascular disease in the upcoming future. If advances continue at this remarkable pace then one can only fathom the extent to which vascular treatment will be reached in the near the future.

Rationale

One cannot ignore the intimate relationship between anatomy and surgery. The surgeon must be able to recreate the anatomy in his/her mind when planning the surgical approach and during the surgery itself. It has become evident after an extensive literature review that knowledge of the arterial anatomy in the lower limb concerning the genicular anastomosis is somewhat lacking. It remains unclear whether the arterial communications occur as a direct connection between two large vessels or if the communication is occurring at a tissue/capillary level between small arterioles. Textbooks tend to illustrate the anastomotic connections as a single, direct communication with no intervening capillaries (Figure 1.), which implies that these anastomoses can be seen with the naked eye and that dissection can easily reveal such connections. However, this model of illustrating arterial anastomoses may be inaccurate when one considers the hemodynamics involved.

If blood is entering a single, continuous vessel from more than one site, it is bound to collide and create turbulence. This inefficient system of blood flow increases energy losses due to friction and thus, is highly disfavoured by the body. Furthermore, crash of blood predisposes aneurysm formation so it is highly unlikely that such connections are occurring.

Therefore, the purpose of this study is to provide a morphological analysis of the communication between the DBLCFA and branches of the SLGA in order to gain further insight into the organization of the genicular anastomosis. The objectives are to: describe the anatomy of the DBLCFA, determine the contribution of the DBLCFA to the genicular anastomosis, and to provide insight into the artery’s anastomotic arrangement.

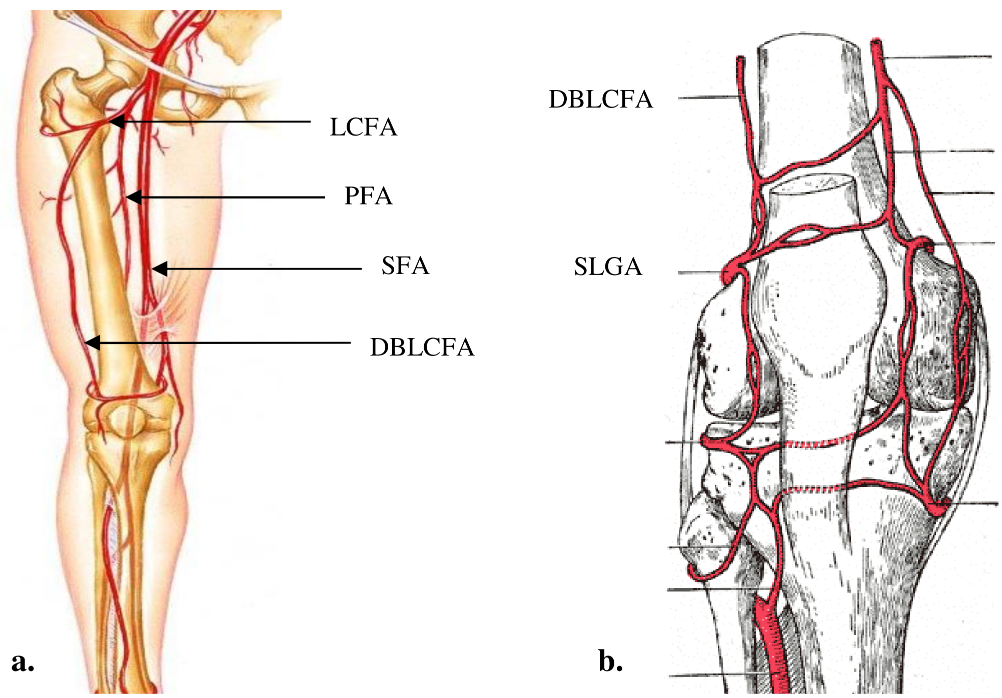


Fig. 1: Typical illustration in anatomy textbooks of the arterial organization in the lower limb. **a.** Schematic from anatomy textbook used in the undergraduate anatomy course at the University of Western Ontario. **b.** Schematic from Grey’s Anatomy.

METHODS

Dissection

Ten lower limbs were graciously donated from the gross anatomy lab in the department of Anatomy and Cell Biology at the University of Western Ontario. All limbs attained were from elderly cadavers (mean age 77.3) whose medical history was unknown. The subjects' age, gender, donor number, and cause of death were recorded. Cadavers with evidence of severe arterial disease were excluded from the study.

Seven of the cadavers were male and 3 were female. The cadavers were injected with 3% formalin through a duotronic embalming machine via the right femoral and left common carotid arteries. Latex was injected via the same arteries with the aid of a high powered air pressure pump.

Anterior approach

The CFA was exposed anteriorly by approximating the mid-inguinal point. An incision was made from the mid-inguinal point, following the inner margin of Sartorius, to the tibial tubercle. At the level of the tibial tubercle, the skin was incised circumferentially allowing the superficial fascia to be reflected and removed. To expose the femoropopliteal segment, intervening muscles, in additional to accompanying nerves and veins, were carefully excised. The femoral sheath was then entered, and major branches of the CFA and SFA were dissected.

The PFA and its major branches were dissected and their branching pattern was noted. The descending branches were identified and followed down the lateral aspect of the thigh deep to rectus femoris and within the substance of vastus lateralis until their diminished size and integrity was deemed unsafe for further dissection without severing the vessels. At this point, the posterior approach was commenced.

Posterior Approach

The popliteal fossa was entered and the popliteal artery was identified by first removing popliteal fat and fascia. The popliteal veins and their tributaries, alongside branches of the sciatic nerve, were removed. The genicular arteries were identified and dissected along most of their course. Branches of the superior lateral genicular artery were followed as they approached branches of the DBLCFA.

Photography

Throughout the dissections muscular branches were removed and photographs of any evidence of arterial anastomosis were taken with a Nikon D80 single-lens reflex digital camera.

<u>3D Reconstruction</u>

AMIRA

Cryosections from the female Visible human data were obtained and inputted into the 3D reconstruction software AMIRA (version 5.1). Once the data was imported into AMIRA, the femoral artery and all of its branches were highlighted with distinct colours and a stereoscopic surface view was generated. After the surface image was smoothed, a picture was taken using the ‘snapshot’ feature. Slices 1865b – 2245a from the thigh were cropped using Adobe photoshop and imported into AMIRA. Slices 1975c – 1981a were omitted due to image distortion. The resultant gap was accommodated for by interpolating slices 1944a – 2011c.

OSIRIX

Full-body, contrast-enhanced CT angiograms were made available from the department of Radiology at University Hospital, University of Western Ontario. The CT data was converted into DICOM format and imported into OSIRIX. A 3D maximum intensity projection (MIP) was then created extending the entire length of the thigh (Appendix 1). Once the appropriate threshold was selected, a snapshot of the 3D image was taken. Slices were 0.625 mm thick and they were reconstructed at 3-5 mm thickness.

Additionally, a sample, contrast-enhanced, MRI data set entitled Matrix was downloaded from the official Osirix website (29) and imported then visualized in imaging software. The data was then exported as a JPEG image file.

Data Collection and Analysis

The anastomoses were classified as: continuous, approaching, or no anastomosis. An anastomosis was determined to be continuous if a single vessel was found to communicate between the superficial and deep femoral arterial system. An anastomosis was determined to be approaching if arteries from each system could be dissected to a common block of tissue. An anastomosis was thought to be unlikely and categorized as no anastomosis if arteries from the superficial and deep systems terminated in different blocks of tissue. Donor number, date and time were used to label all photographs. Data was entered into a Word file immediately after dissection and photography. It is anticipated that the small sample size will preclude formal statistical analysis.

RESULTS

The average age of the dissected cadavers was 77.3 with a range of 53-88. There was no correlation between gender and branching pattern of DBLCFA. There was also no correlation between gender and type of anastomosis observed (i.e. continuous, approaching, no anastomosis). Patients with cardiovascular disease did not exhibit a particular type of DBLCFA branching nor did they manifest a specific type of anastomosis. Of the 3 cadavers with cardiovascular disease, 2 exhibited an 'approaching' type of anastomosis and 1 exhibited 'continuous'. All anastomoses classified as 'continuous' were observed in males whereas 2 of the 3 females exhibited an 'approaching' type of anastomosis. The two cadavers that did not exhibit an apparent anastomosis died of cancer and were the least old (53 and 69).

Table 1. Cause of death, DBLCFA branching Type, and genicular anastomosis class of the 10 cadavers dissected.

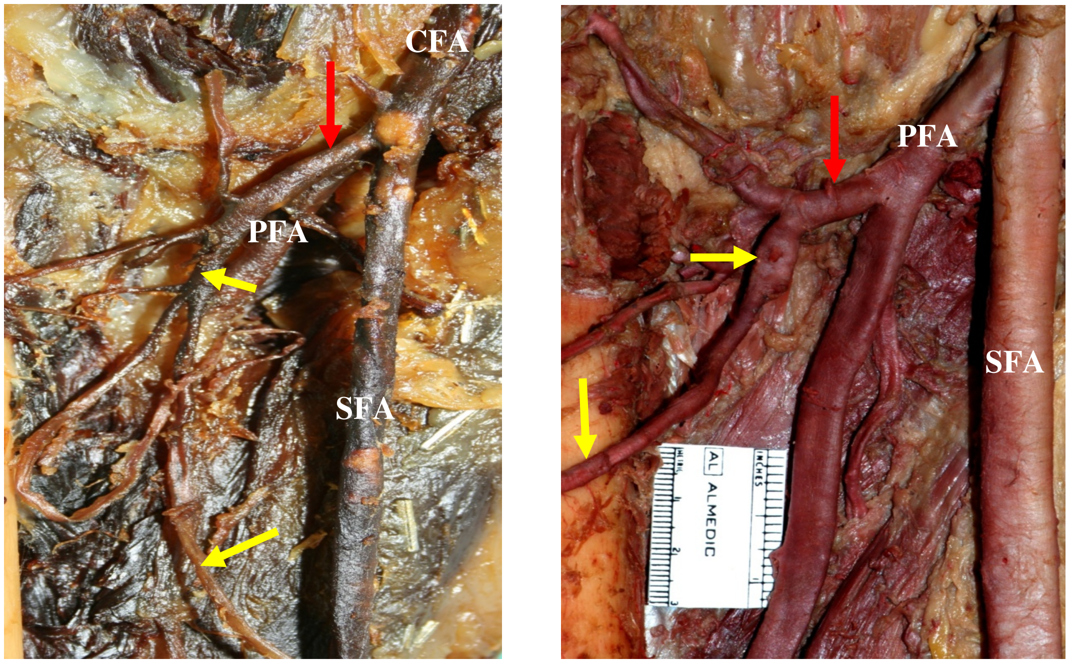
Donor Number	Sex	Age	Cause of Death	DBLCFA Type	Genicular Anastomosis
1341	M	69	Cardiorespiratory failure, palliation, **middle cerebral artery infarct**	1	Continuous
1358	M	84	Metastatic renal cell carcinoma	2	Continuous
1373	M	69	Cancer of esophagus	4 & 5	No anastomosis
1382	F	53	Non small cell lung cancer	1	No anastomosis
1409	M	83	Intracerebral hemorrhage, accidental fall	2	Approaching
1413	F	88	Natural causes, hypertension	5	Approaching
1427	M	81	GI bleed, bladder cancer, chronic renal failure, congestive heart failure, bilateral pleural effusion	4	Continuous
1428	F	86	**Arteriosclerotic heart disease**, chronic heart failure, atrial fibrillation	3	Approaching

1430	M	87	Pneumonia, stroke	4	Approaching
1434	M	73	Heart failure, lung cancer, **arteriosclerotic heart disease**, chronic obstructive pulmonary disease	2	Approaching

<u>*Dissection*</u>

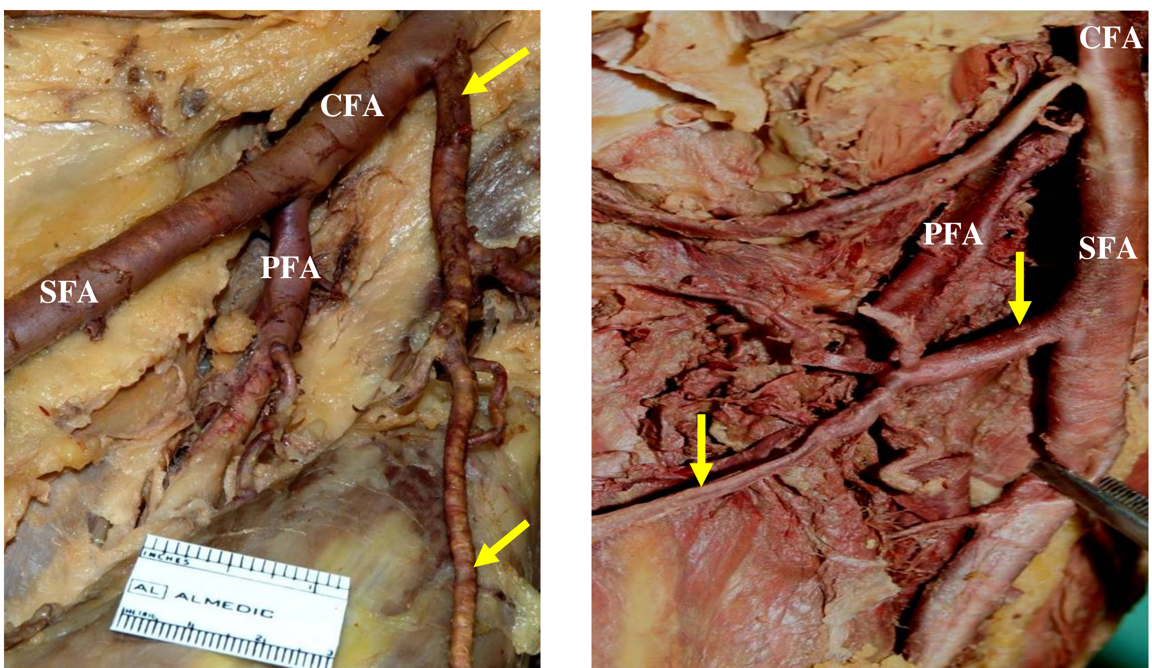
Branching Pattern of DBLCFA

There was considerable variation in the arterial anatomy of the thigh, specifically, in the branching pattern of the DBLCFA. The DBLCFA was observed in 5 arrangements based on its parent trunk. In Type 1 (1 limb), the DBLCFA was given off from the LCFA, which in turn originated from the CFA (figure 2). In Type 2 (4 limbs), the pattern was similar to Type 1 except that the LCFA branched from the PFA (figure 2). In Type 3 (4 limbs) and Type 4 (1 limb), the DBLCFA was given off from the CFA and the SFA, respectively (Figure 3). In Type 5 (1 limb), the DBLCFA branched from the PFA (figure 4). In one limb, there were 2 DBLCFAs, one arising from the PFA and one arising from the SFA (figure 4). Thus, it is possible that if more than 1 DBLCFA exists, the multiple branches may have separate origins.



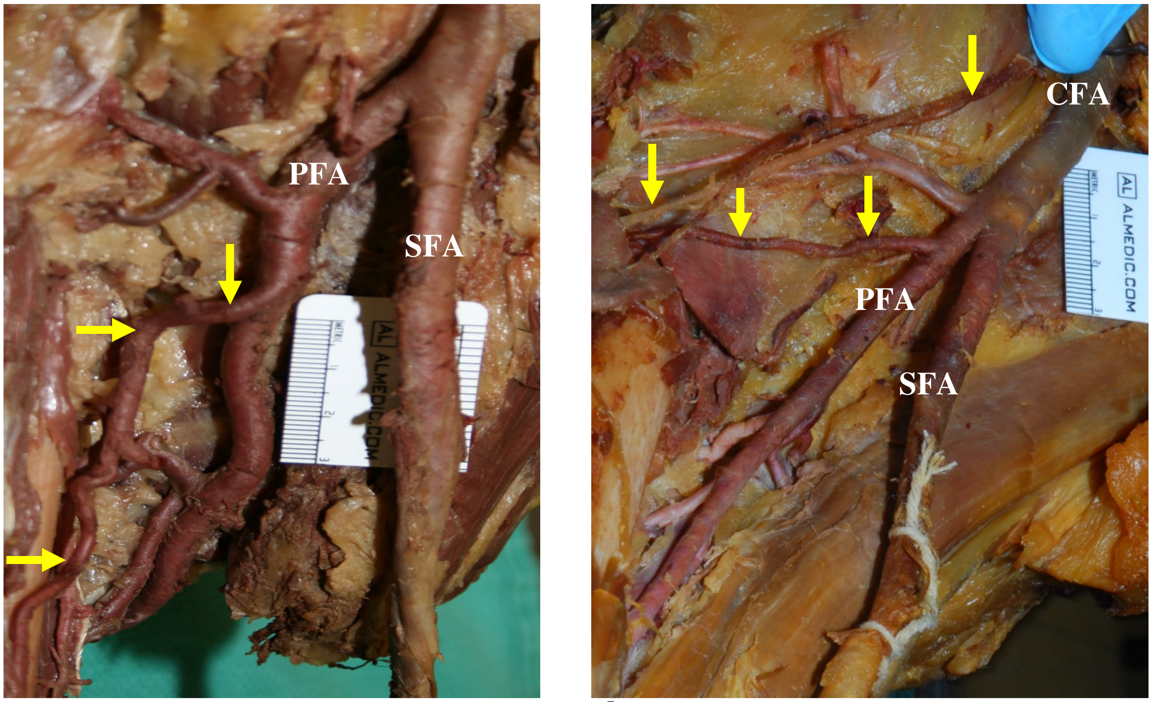
a. b.

Fig. 2: **a.** Type 1 branching of the DBLCFA (yellow arrows) in the right limb. The LCFA (red arrow) can be seen branching from the CFA. **b.** Type 2 branching of the DBLCFA (yellow arrows) in the right limb. The LCFA (red arrow) is seen branching from the PFA.



a. b.

Fig. 3: **a.** Type 3 branching of the DBLCFA (yellow arrows) in the left lower limb. The DBLCFA is branching from the CFA. **b.** Type 4 branching of the DBLCFA (yellow arrows) in the right lower limb. The artery is seen branching from the SFA.



a. b.

Fig. 4: **a.** Type 5 branching of the DBLCFA (yellow arrows) in the right lower limb. The DBLCFA is seen branching from the PFA. **b.** Type 4 and Type 5 branching seen in the right lower limb. The DBLCFAs (yellow arrows), 2 in this case, are seen branching from CFA (Type 4) and the PFA (Type 5).

Anastomoses

Of the 10 lower limbs dissected, a clear anastomosis between the DBLCFA and branches of the superior lateral genicular artery (SLGA) was seen in 3 limbs (Figure 4). In 5 limbs, the two arteries were clearly approaching each other, but a discernible communication was not seen (Figure 5). In the remaining 2 limbs, there was no evidence suggesting the two arteries may be communicating.

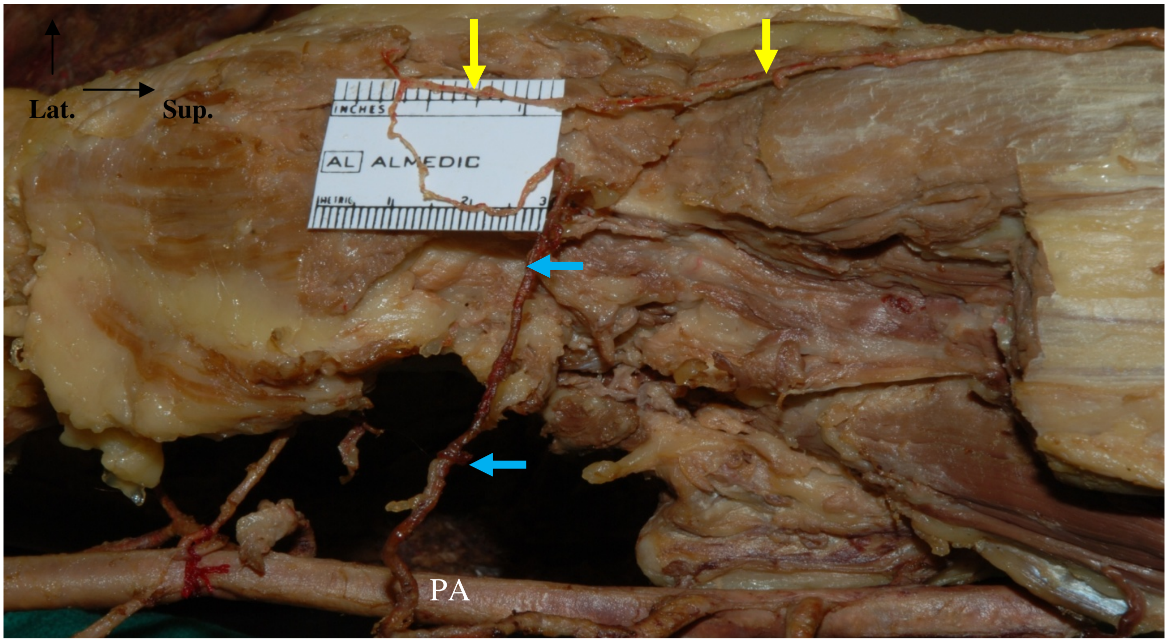


Fig. 5: Posterior view of the left popliteal fossa showing the DBLCFA (yellow arrows) anastomosing with SLGA (blue arrows). PA: popliteal artery.

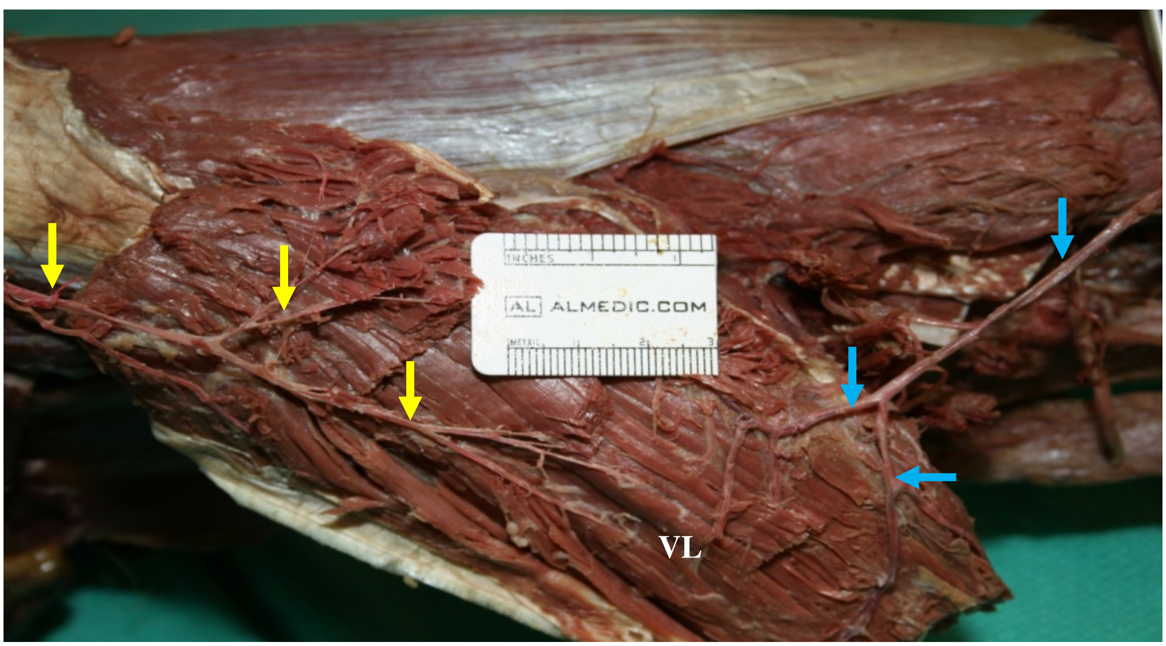


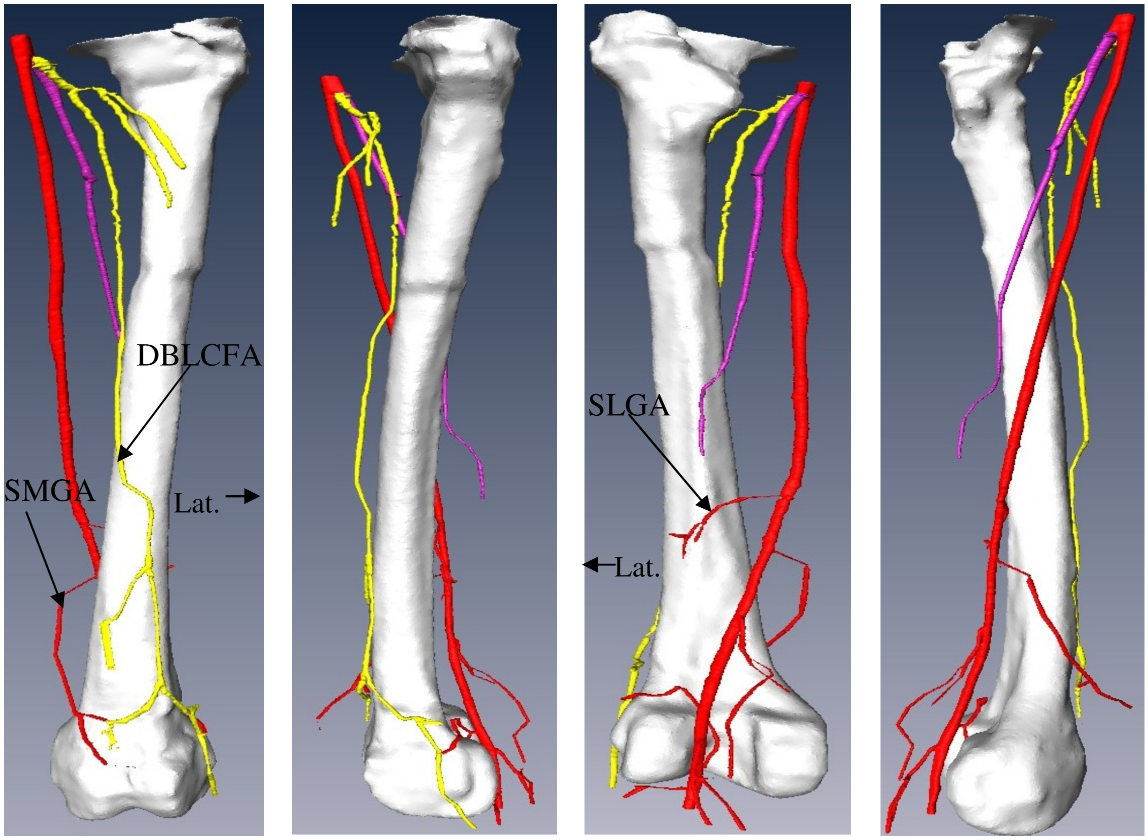
Fig. 6: A section of vastus lateralis (VL) has been rotated 180° and reflected on its anterior surface. DBLCFA (yellow arrows) can be seen approaching SLGA branches (blue arrows)

Fig. 7: No evidence of anastomosis. DBLCFAs (yellow arrows) terminate at a distance from branches of the SLGA.

<u>*3D Reconstruction*</u>

AMIRA

Figure 8 illustrates the 3D model created in AMIRA using cryosections from the female visible human. The model illustrates a Type 1 branching pattern in which the DBLCFA is a branch of the LCFA, which in turn is a branch of the CFA. The DBLCFA can be seen descending along the entire length of the anterior surface of the femur medial to what would be expected. It then sends anastomosing branches to the superior medial genicular artery (SMGA) just above the condyles of the femur, and the inferior lateral genicular artery (ILGA) at the level of the lateral condyle. The SLGA was not followed to its entirety due to difficulties in following arteries this low down in the thigh. Compounding this difficulty were unexpected data distortions in slices 1975c – 1981a.



a. b. c. d.

Fig. 8: Arterial 3D reconstruction using cryosections from the female visible human in AMIRA of the right thigh. (**a.** anterior **b.** lateral **c.** posterior **d.** medial views). Legend: red = femoral, popliteal, genicular arteries; purple = profunda femoris artery; yellow = branches of the lateral circumflex femoral artery.

Osirix

A full body CT angiogram was made available from the radiology department at University Hospital, London, ON and imported into the 3D imaging software, Osirix. The 3D model was not able to illustrate the arteries of interest. However, a sample data file was downloaded from the Osirix website and is provided in Figure 7. Note that Figure 7 shows no signs of communication between the DBLCFA and the SLGA.

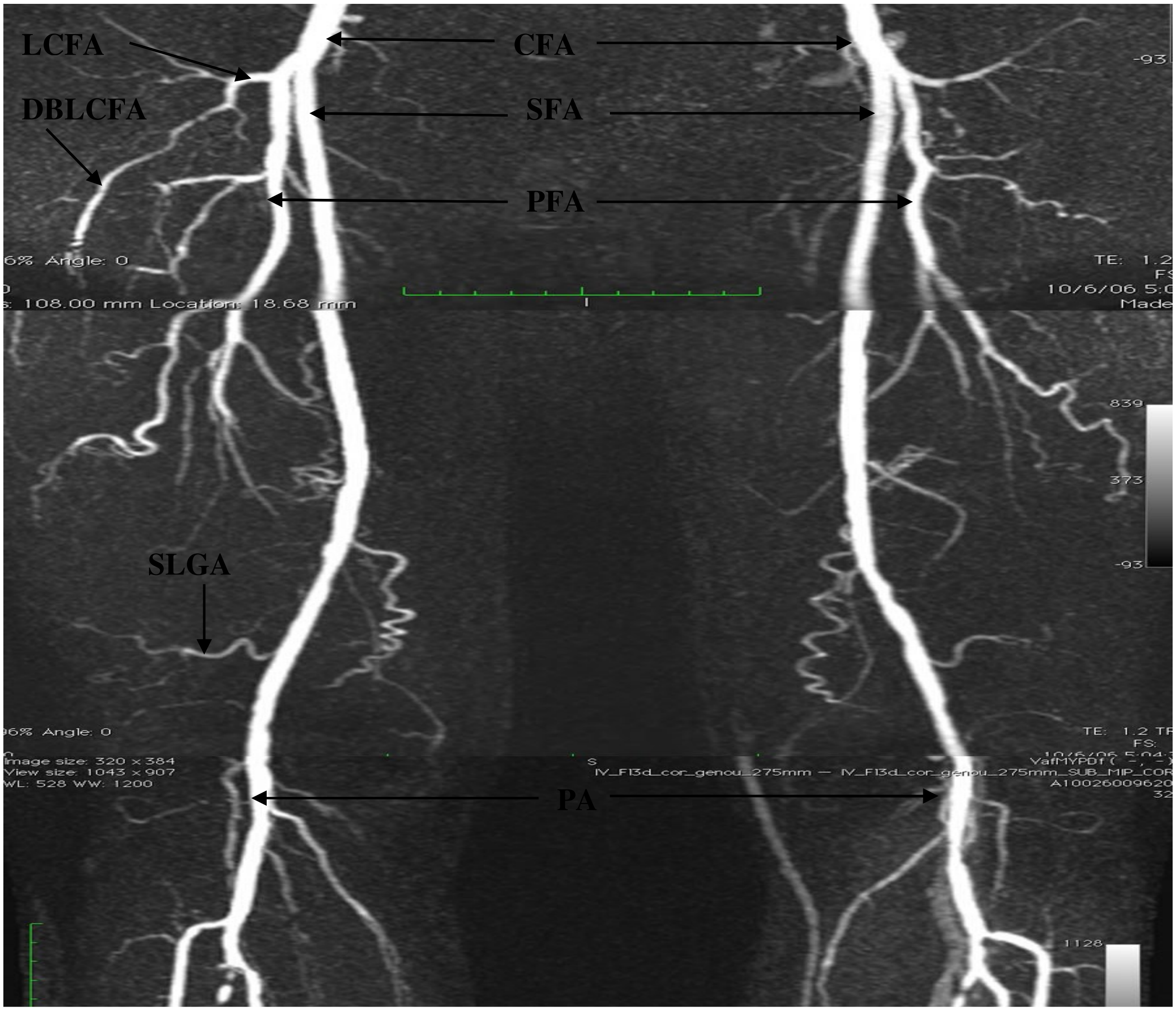


Fig. 9: A 3D MIP (maximum intensity projection) of contrast-enhanced MRI data showing arteries of the anterior thigh in right and left limbs.

DISCUSSION

The aim of this study was to describe the anatomy of the DBLCFA, to determine if it has the potential to become involved in collateral circulation and to provide insight into the artery's anastomotic arrangement. In terms of its anatomy, the DBLCFA was not consistent in its branching pattern. Its parent trunk varied and included the CFA, PFA, LCFA and the SFA. These results are similar to those of Fukuda et al. (12) who performed preoperative digital subtraction femoral arteriography in 132 patients to investigate the anatomical variants of the LCFA. They found that in 78% of the limbs the LCFA originated from the PFA, including a pattern in which a major branch of the LCFA arises separately from the PFA. Although the authors did not comment which of the branches is most likely to arise separately from the PFA, our results suggest that it is the DBLCFA. Fukuda et al. (12) also found that the DBLCFA can arise from the CFA or the SFA, results that mirror some of the findings in this study. Similarly, Massoud and Fletcher (23) found in their angiographic study of 94 patients that a branch of the LCFA may arise from the SFA. Thus, surgeons concerned with harvesting the DBLCFA need to be aware that it is not always a branch of the LCFA. In fact, our study demonstrated that the DBLCFA exhibited typical textbook anatomy in only 3 out of the 10 limbs.

Therefore, the common description of the DBLCFA's anatomy is simplified and possibly borrowed over time. Proper understanding of this anatomy is important because of its utilization in coronary artery bypass (33) and in reconstructive surgeries involving the anterolateral thigh free flap (ATF). The ALT flap is often used in reconstructive surgeries in patients with head and neck cancers and relies on the DBLCFA as the inflow of its vascular pedicle. However, interruption of the DBLCFA in patients with a predisposition to vascular disease has the potential to cause the critical lower limb ischemia due to the artery's important contribution to the genicular anastomosis (17). Furthermore, the involvement of the DBLCFA in collateral circulation makes it a prime target for the injection of growth factors that promote arterial remodelling in situations of acute trauma to the SFA. This may allow for faster sprouting of collaterals, which in theory should relieve the lower limb from ischemia. Due to the artery's important clinical relevance, a sound understanding of its anatomy is essential.

We are proposing the following description of the artery's anatomy. The DBLCFA can have multiple origins and more than one branch of this artery may arise. The DBLCFA may arise from the CFA, SFA, PFA, or the LCFA, and when more than one branch exists, the two branches need not arise from the same artery. In the first 3-5 cm of its course, the artery lies in plain view within fascia underneath rectus femoris and can be found medial to vastus lateralis. As the artery descends, it moves successively laterally towards vastus lateralis sending out numerous muscular branches before it becomes embedded in the substance of the muscle. Within vastus lateralis, the artery continues to descend and to gives rise to small nutrient arteries to the muscle around it. Approximately 2/3 down the thigh, the artery become significantly diminished in size and terminates in vastus lateralis. Before its termination, the DBLCFA may give rise to tiny anastomotic arterioles that join branches of the SLGA (figure 10).

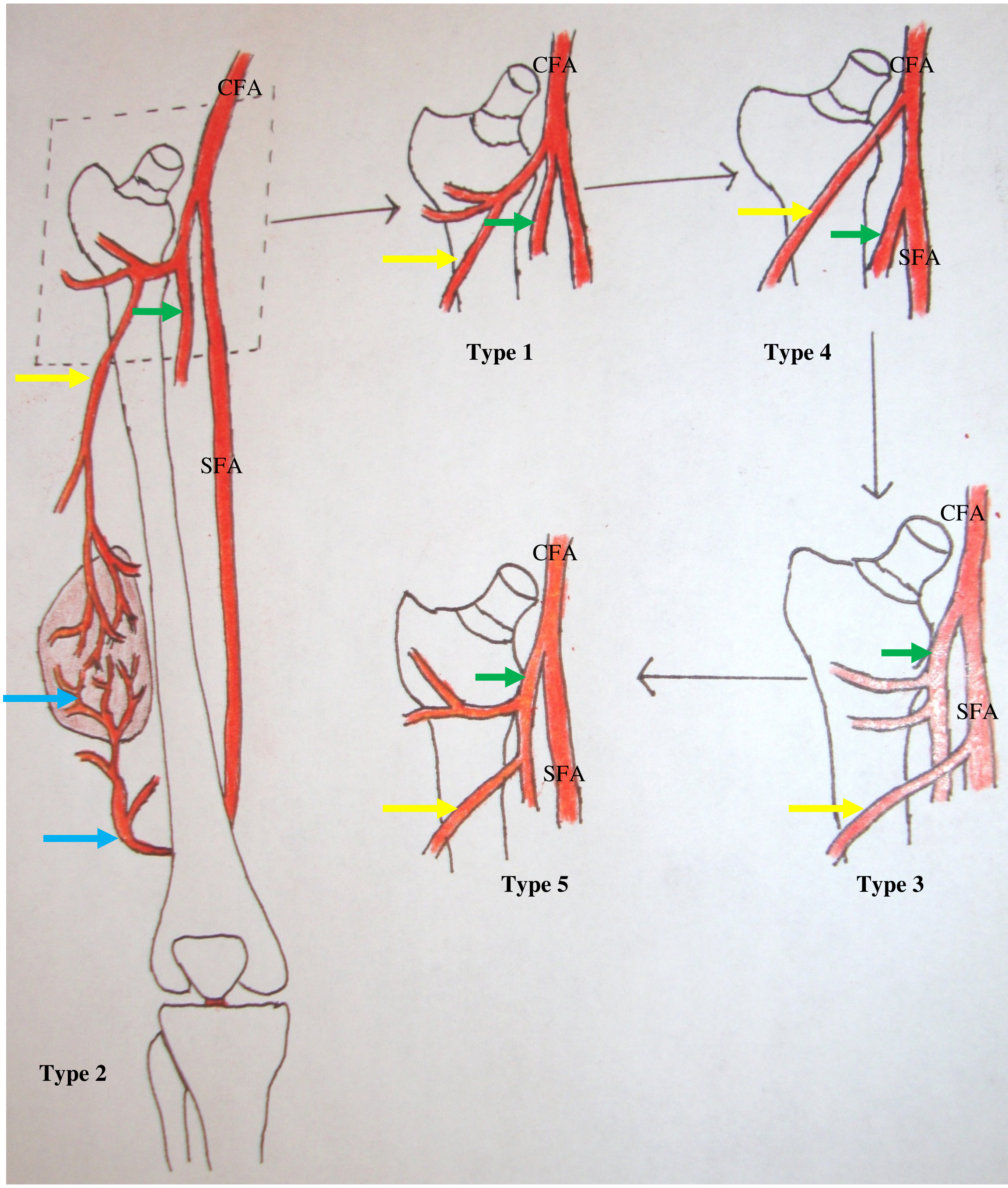


Fig. 10: Schematic representation illustrating what our results suggest the anatomy of the DBLCFA should look like. All possible variations are represented. (yellow arrows = DBLCFA, blue arrows = SLGA, green arrows = PFA)

In terms of the morphology of the observed anastomoses, the DBLCFA manifested two possible types of communications. In the first type (figure 4), a small branch of the DBLCFA was seen directly joining a branch of the SLGA. This communication occurred within the substance of vastus lateralis. Although only one branch of each artery seemed to have been involved in this anastomosis, it is possible that multiple branches may have been involved, but were either destroyed during dissection or were too small to be seen.

In the second type of anastomosis (figure 5), branches of the DBLCFA and SLGA clearly approached each other, occupied the same muscular bed, but no clear communication was seen. The communications might be occurring at a capillary level; however, as can be imagined, dissection at this microscopic level is not feasible. Alternatively, the vessels may not be connecting at all in a disease-free limb, but should the limb become ischemic, tiny collaterals may emerge and connect the DBLCFA with the SLGA.

Finally, it is possible that the two types of anastomoses observed are in fact a single type. It could be that solely by chance, we were able to dissect communicating branches in certain limbs but not in others. It became clear from dissecting all ten limbs that the size of arteries varied from limb to limb. Thus, limbs that inherently exhibited larger arteries may have allowed for an easier dissection leading to an increase chance of finding small anastomosing branches.

Our sample size is too small to draw conclusions regarding mechanism by which the different types of anastomoses are developed. Our subjects were elderly and some died of cardiovascular disease. However, we excluded overt peripheral vascular disease. We are able to conclude that communication between the superficial and deep femoral arterial systems exist in some people without obstruction of the SFA, but we cannot determine the factors related to the presence of these anastomoses.

Our study also implemented 3D technology to supplement the anatomy observed during dissection. It became clear that imaging has not yet reached the level of resolution that dissection is able to provide. Even with the female visible human project, where slices were only 0.3 mm apart, the detailed anatomy of the genicular anastomosis was difficult to visualize. Furthermore, approximately 4 mm of data was lost due to data distortion in 14 (1975c – 1981a) thigh cryosections (Appendix 4).

3D images were also constructed using Osirix. When a 3D MIP is created using contrast-enhanced CT angiograms from a live patient as the source data, the 3D model was not able to illustrate the arteries in question (Appendix 2 and 3). However, the DBLCFA and the SLGA were visualized in a detailed 3D model created from sample data downloaded from the Osirix website. Despite the source data exhibiting high resolution, a connection between the DBLCFA and the SLGA was not observed. This may be attributed to the fact that MRI provides a functional view of arterial anatomy. If no blood is flowing through the tiny arterioles that connect the DBLCFA with the SLGA, the MRI would not pick up these arterioles and as a result, no connection will be observed. According to our dissection, these arterioles are so small that resolution can be lost due to inadequate blood flow through these tiny vessels.

LIMITATIONS

The sample size used in this study was only 10; therefore, not all possible origins of the DBLCFA may have been illustrated. The small sample size also prevented any statistic analyses to be conducted. Nonetheless, even with this small sample size, 5 different origins of the DBLCFA were noted, and although with a larger sample size some correlations might emerge, the random nature of the observations made in this study make such correlations unlikely. Also, the techniques used to observe the anastomoses are inherently different: dissection allowed an external view of the anatomy, AMIRA allowed for an internal view (by highlighting the lumen), and contrast MRI/CT allowed a functional view of the anatomy (by tracing the flow of blood). Moreover, the resolution of the CT scan was low (0.625 mm), which made viewing small collaterals impossible. Although the resolution of the female Visible Human data was twice as high as that of the CT data, viewing small arteries and collaterals was extremely difficult. Many small arteries are tortuous, and in a horizontal plane, such arteries might disappear in one slice then reappear in the next making the tracing of these arteries extremely challenging. Also, the size of the small arteries was exaggerated when attempting to highlight the lumen. If the actual size of the small arteries was highlighted the vessels would appear chopped and discontinuous when viewed in 3D. Finally, dissection is limited by its destructive nature and some anastomotic branches may have been lost as a result. In an attempt to counter than, vessels were dissected from proximal and distal points allowing the intervening tissue to be maintained.

PROSPECTS FOR FUTURE RESEARCH

Further studies may confirm the presence of microscopic connections by injecting tracers at points proximal and distal to the site of anastomosis and observing if the tracers meet. Furthermore, dissection could be complimented by histology allowing one to start with a gross view of the anatomy and end with a microscopic view. However, with microscopic anatomy the field of view is very limited and the problems observed in tracing vessels grossly will be magnified in histology. Alternatively, a vessel cast can be created and has great prospects in showing very fine anatomy. The process would require vessels be pumped with silicon rubber at two different sites, preferentially each site with its own coloured rubber, and then immersed in a bath to dissolve away extra tissue. Since it would be difficult to place an entire body in such a bath, it is suggested by our results that only the lower limb from mid-thigh to the tibial tubercle is required to demonstrate the genicular arterial anastomoses.

CONCLUSION

The results indicate that the current anatomy of the DBLCFA, especially in how it is involved in the genicular anastomosis is simplified. We propose that anatomy texts begin to include a description of all possible variations. Also, since the DBLCFA does not always emerge from the LCFA, we propose that the artery be renamed to the lateral descending artery of the thigh (LDAT). Finally, the connection between LDAT and SLGA is not as straightforward as anatomy and surgery textbooks make it out to be. LDAT gives rise to numerous small arterioles, which may connect with branches of the SLGA in a disease free limb.

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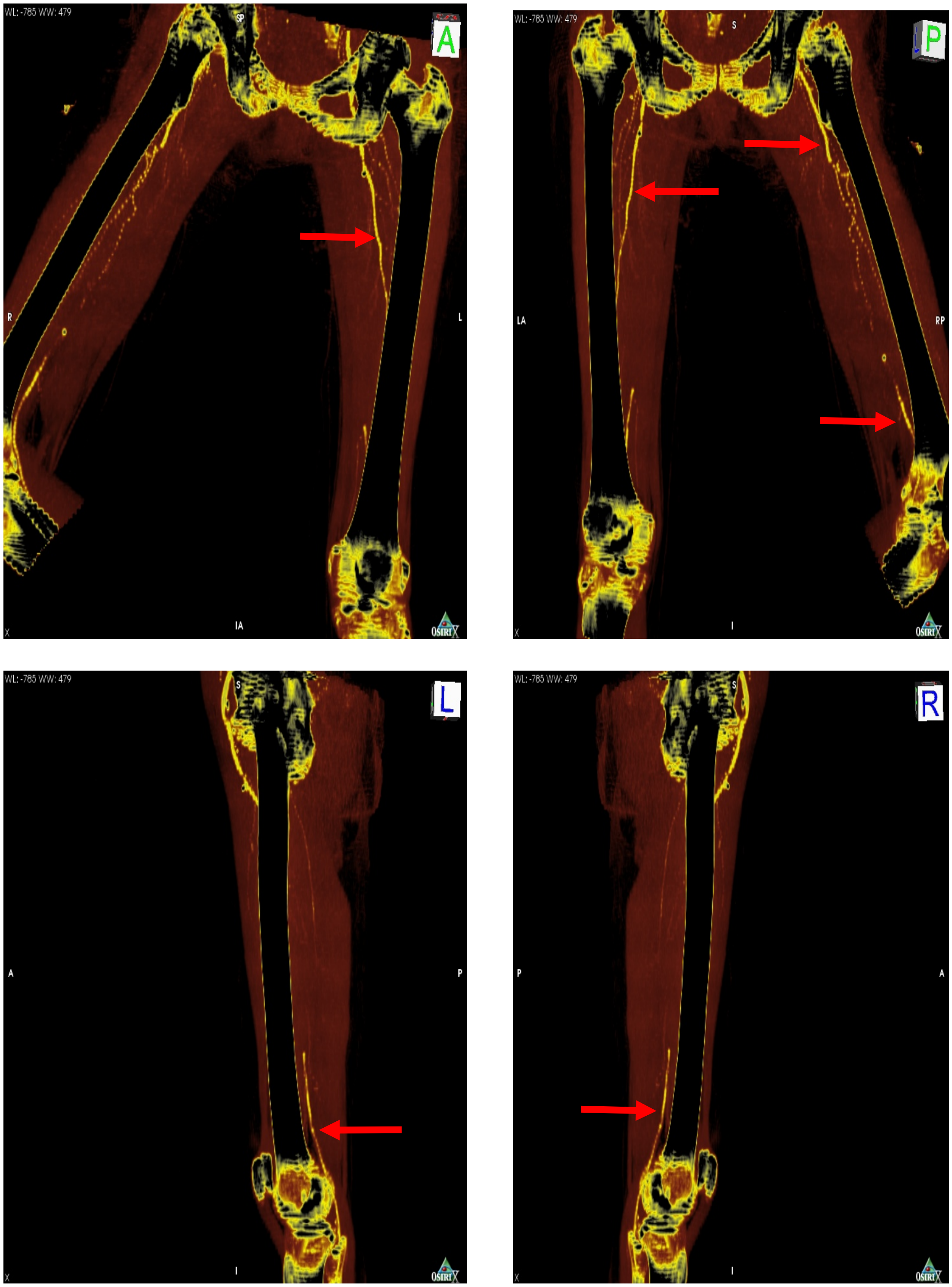
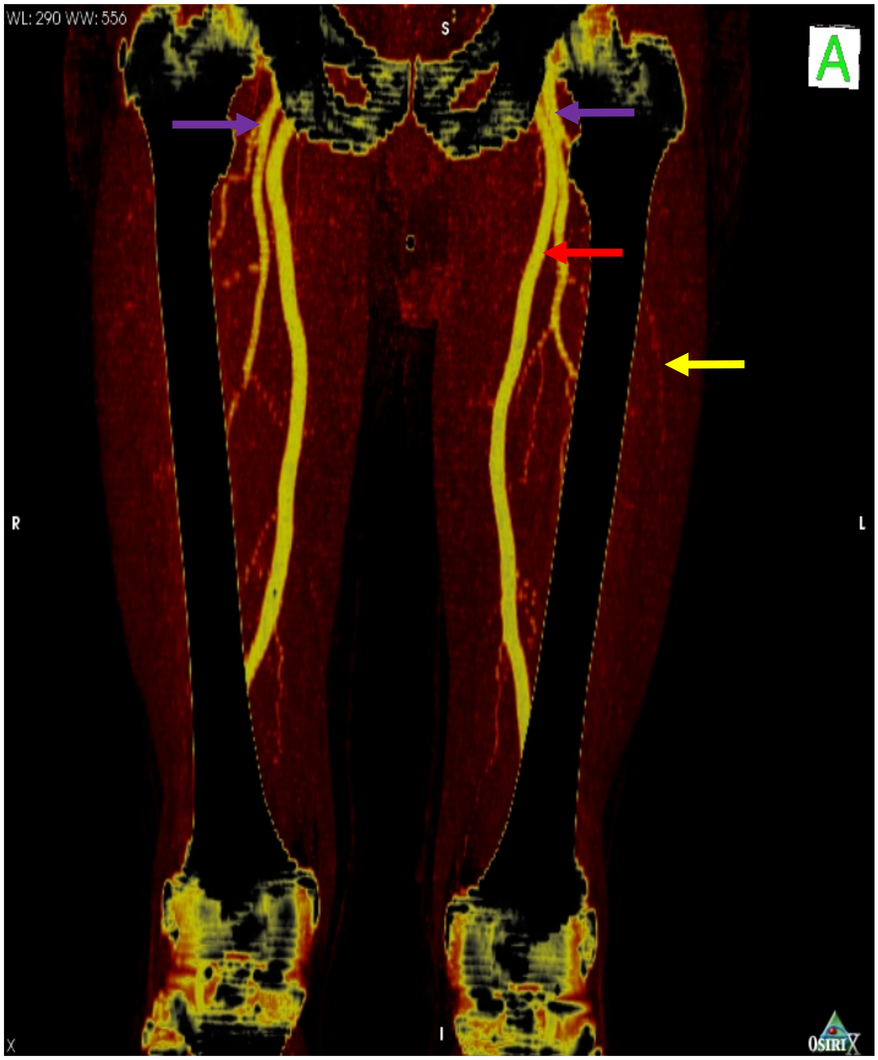
APPENDIX 1



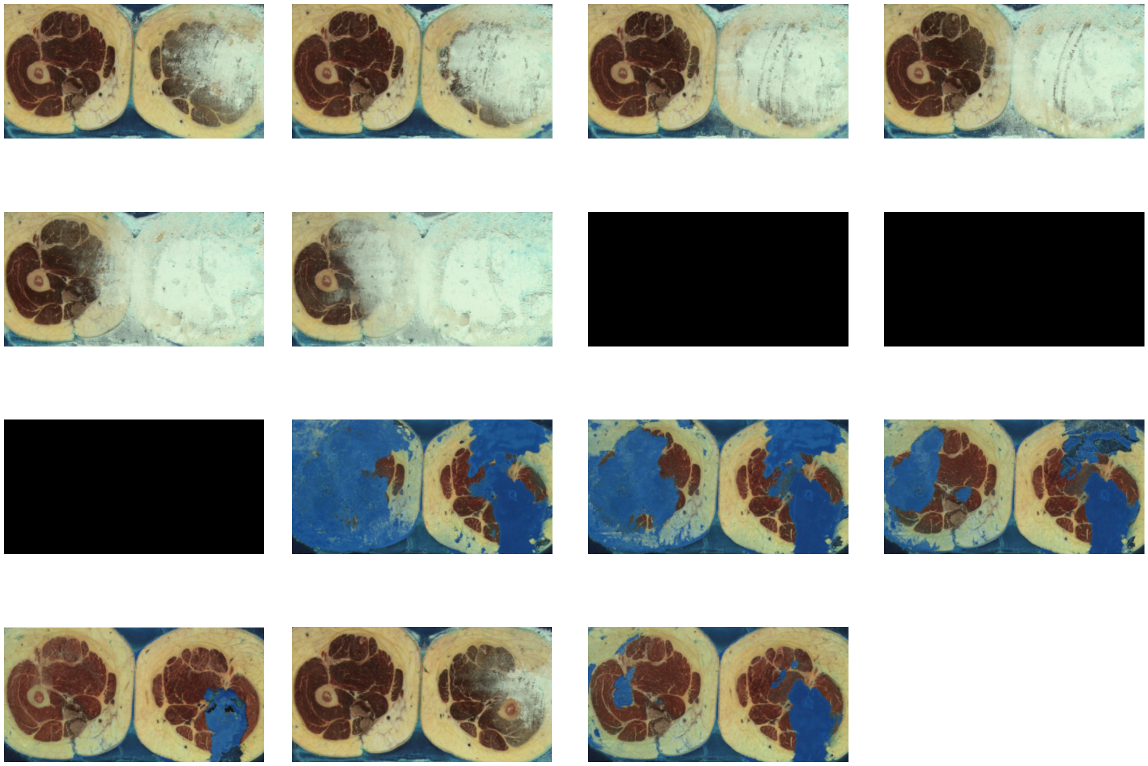
3D image of contrast-enhanced CT angiography runoffs imported in OSIRIX. The femoral/popliteal artery (red arrows) are the only vessels seen. The DBLCFA cannot be visualized.

APPENDIX 2



An anterior 3D MIP of the arteries in the thigh created from sample data from the OSIRIX website. The PFA (purple arrow) can be seen branching and its branches can be visualized. The DBLCFA is obscure, but may be indicated by the yellow arrow. No anastomosis is visible.

APPENDIX 3



Distorted images from the thigh of the female visible human.

Maher Sabalbal

BMSc, MSc candidate

University of Western Ontario

Education

2008 – present	University of Western Ontario, London, Ontario **Masters of Science** – Clinical Anatomy Expected graduation date: May, 2010
2004 – 2008	University of Western Ontario, London, Ontario **Bachelors of Medical Science** – Honours Medical Science

Research

May ‘09 – May ‘10 **Masters of Science Thesis, University of Western Ontario, department of Anatomy and Cell Biology**

Supervisor: Vivian McAlister, MD, FRCPC
University Hospital, University of Western Ontario
Division of General Surgery, Department of Surgery

This research combines 3D reconstruction with cadaveric dissection to study the anatomy of the collateral circulation around the knee joint. The focus of the study was to provide a clear depiction of the involvement of the descending branch of the lateral circumflex femoral artery (DBLCFA). Data from the visible human project and data from CT angiograms were used as templates for 3D reconstruction. Ten lower limbs were dissected, the anatomy of DBLCFA was described and its anastomotic morphology was illustrated.

Sept. ‘08 – Nov. ‘08 **Virtual Reality Imaging with real time ultrasound for percutaneous spinal interventions**

Primary Author: Collin F. Clarke, MD
Department of Anesthesia and Perioperative Medicine
University of Western Ontario

The purpose of this study was to demonstrate the accuracy of virtual imaging to guide a 17 gauge Tuohy needle to predefined targets within a cadaveric torso spine. The study may allow 3D imaging to guide future epidural administrations and possibly replace today’s “blind” approach. My role was to reconstruct vertebral bodies L1-L4 using data from cadaveric CT scans in the 3D imaging software AMIRA.

Abstracts and Publications

April 25 – 27, 2010	American Association of Anatomists, Anaheim, CA
March 31, 2010	Margaret Moffat Research Day, University of Western Ontario, London, ON
In press	Clarke C, Moore J, Wedlake C, Lee D, Ganapathy S, Sabalbal M, Wilson T, Peters T, Bainbridge D. Virtual Reality Imaging with Real Time Ultrasound Guidance for Facet Joint Injection – A Proof of Concept. *Anesthesia and Analgesia.*

Work Experience

2004 – present	**Canadian Forces Army Reserves, 4th Battalion the Royal Canadian Regiment, Wolsey Barracks, London, ON, Canada –** Attend training sessions once a week and accompany the unit on monthly weekend exercises. Military qualifications include: basic infantry qualifications, military first aid, Personal Leadership Qualifications.
2008 – 2010	**Teaching Assistant, Cadaveric Gross Anatomy, University of Western Ontario, Department of Anatomy and Cell Biology –** Prepare laboratory demonstrations for undergraduate students in anatomy as well as for first and second year medical students. Other duties include: grade assignments and laboratory reports, proctor exams and conduct review sessions.
Jul '07 – Sept. '07	**Program Evaluator, Geriatric Psychiatry, Regional Mental Healthcare London, London, ON, Canada –** Use data analysis software, SPSS, to conduct evaluations for newly implemented programs such as: Gentle Persuasive Approach, Barriers to Discharge, Falls and Assault. Work with clinical psychologists to perform clinical chart reviews.

Extracurricular Activities

Transplant Team – On-call to provide assistance to the Multi-Organ Transplant Team at the London Health Sciences Centre, Department of Surgery, University of Western Ontario, London, ON, Canada.
Surgery Observerships – Robotic cardiac bypass, thyroidectomy, laryngogotomy, liver transplant.