Absence of the genicular arterial anastomosis as generally depicted in textbooks

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ABSTRACT

INTRODUCTION Textbook representations of the genicular arterial anastomosis show a large direct communication between the descending branch of the lateral circumflex femoral artery (DBLCFA) and a genicular branch of the popliteal artery but this is not compatible with clinical experience. The aim of this study was to determine whether the arterial anastomosis at the knee is sufficient, in the event of traumatic disruption of the superficial femoral artery, to infuse protective agents or to place a stent to restore flow to the lower leg.

METHODS Dissection of ten cadaveric lower limbs was performed to photograph the arterial anatomy from the inguinal ligament to the tibial tubercle. Anastomosis with branches of the popliteal artery was classified as: 'direct communication', 'approaching communication' or 'no evident communication'.

RESULTS A constant descending artery in the lateral thigh (LDAT) was found to have five types of origin: Type 1 (2/10 limbs) involved the lateral circumflex femoral branch of the femoral artery, Type 2 (3/10 limbs) the lateral circumflex femoral branch of the profunda femoris artery, Type 3 (1/10 limbs) the femoral artery, Type 4 (3/10 limbs) the superficial femoral artery and Type 5 (2/10 limbs) the profunda femoris artery. In one limb, there were two descending arteries (Types 4 and 5). Collateral circulation at the knee was also variable: direct communicating vessels (3/10 limbs); approaching vessels with possible communication via capillaries (5/10 limbs); no evident communication (2/10 limbs). Communicating vessels, if present, are too small to provide immediate collateral circulation.

CONCLUSIONS Modern representations of the genicular arterial anastomosis are inaccurate, derived commonly from an idealised image that first appeared *Gray's Anatomy* in 1910. The afferent vessel is not the DBLCFA. The majority of subjects have the potential to recruit collateral circulation via the LDAT following gradual obstruction to normal arterial flow, which may be important if the LDAT is removed for bypass or flap surgery. A direct communication is rarely present and is never as robust as generally depicted in textbooks.

KEYWORDS

Anatomy – Femoral artery – Popliteal artery – Penetrating trauma – Military medicine

Accepted 10 January 2013

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Combat injuries of the thigh often involve the superficial femoral artery (SFA), the conduit artery to the leg. It is our experience that angiography to delineate acute SFA injury in these situations sometimes shows contrast reconstitution of the popliteal artery below the SFA obstruction. While chronic occlusion of the SFA may allow for collateral circulation of blood to develop, acute disruption relies on anatomical anastomoses, which are already present, to divert blood to the lower leg. We hypothesised that non-surgical treatment of lower limb ischaemia from SFA disruption is possible by the infusion of agents or the placement of stents in a genicular arterial anastomosis.

These anastomoses are not usually visible with clinical imaging including direct angiography, computed tomography angiography (CTA) or magnetic resonance angiography

(MRA). All of the surgical or anatomical textbooks that we surveyed demonstrate arterial anastomoses at the knee using strikingly similar illustrations. These diagrammatic representations appear to be based on an illustration that was included for the first time in the 18th American edition of *Gray's Anatomy* from 1910 (Fig 1).¹

Even though this 1910 illustration is similar in style to the other figures, which are drawings of dissections, it was not until the 32nd edition in 1968 that the figure was labelled a 'schematic' to distinguish it from the life drawings.² The schematic and its modern versions show medial and lateral arterial anastomoses at the knee.³ The medial anastomosis, via the descending genicular artery (formerly called anastomotica magna), whose origin is the SFA at Hunter's canal, is too distal to permit collateral flow if the SFA is injured

Figure 1 This figure of the genicular anastomosis, as depicted in editions of *Gray's Anatomy* since 1910,¹ has been the basis for most modern illustrations of this anatomy, which the current study finds to be inaccurate

Figure 2 Five types of lateral descending artery of the thigh (white arrows) as determined by its origin: Type 1 (upper left panel) involves the lateral circumflex femoral artery (CFA) (green arrow), a branch of the femoral artery; Type 2 (upper middle panel) the lateral CFA, a branch of the profunda femoris artery (PFA); Type 3 (upper right panel) the CFA; Type 4 (lower left panel) the superficial femoral artery (SFA); and Type 5 (lower middle panel) the PFA. The dissection in the lower right panel shows two descending arteries (Types 4 and 5).

in the thigh. The afferent vessel of the lateral anastomosis is the descending branch of the lateral circumflex femoral artery (DBLCFA), which ends by direct communication with the lateral superior genicular branch of the popliteal artery.

These illustrations suggest that collateral flow via the genicular anastomosis would be sufficient to supply the leg if the SFA is occluded acutely but this is rarely the case in trauma. This fact, coupled with the possibility that the illustrations are being copied from one textbook to the next, throws our understanding of collateral arterial flow at the knee into doubt. Uncertainty regarding the DBLCFA and its role in the genicular arterial anastomosis should be resolved if this vessel is to be used as a graft in bypass or free flap surgery.⁴ It was our hope, undertaking this research, that anatomic knowledge of the genicular anastomosis would assist the development of non-surgical treatments of traumatic interruption of SFA flow that might be useful in combat situations.

Methods

Prior to commencing this study, we tested three-dimensional (3D) reconstruction of anatomic cryosections or cross-sectional images by CTA or MRA and found all to have insufficient detail to disprove the presence of an anastomosis. Contrast-enhanced studies failed because absence of flow via anastomoses may have been due to preferential flow via regular channels. Manual 3D reconstruction of anatomic cryosections failed because we lost track of secondary and tertiary arteries well above the knee. Traditional anatomic dissection of cadavers provided more detail and greater reliability.

This study was approved according to the guidelines of the Department of Anatomy and Cell Biology at Western University, Canada. The subjects' age, sex and cause of death were recorded. Young subjects were not available. Cadavers without evidence of severe arterial disease on inspection were included in the study. Donors were not sequential but chosen according to availability with respect to teaching requirements in the laboratory. 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. Each stage of dissection was photographed with a D80™ digital single lens reflex camera (Nikon, Kingston upon Thames, UK).

Superior approach

The femoral artery was exposed anteriorly by incision from the midinguinal point, following the medial margin of Sartorius, to the tibial tubercle. The femoral sheath was opened and major branches of the common femoral artery (CFA) and SFA were dissected. At the level of the tibial tubercle, the skin was incised circumferentially, allowing the superficial fascia to be reflected and removed. The profunda femoris artery (PFA) and its major branches were dissected, and their branching pattern was noted. The muscles, nerves and veins were mobilised or excised to expose the femoropopliteal arterial segment. The descending branches were identified and followed down the lateral aspect of the thigh deep to the rectus femoris and within the substance of the

Table 1 Cause of death, type of origin of lateral descending artery of the thigh and genicular anastomosis class of the ten cadavers dissected

Donor number	Age/sex	Cause of death	Origin of afferent artery	Genicular anastomosis
1341	69 M	Middle cerebral artery infarct	Type 1	Direct communication
1358	84 M	Metastatic renal cell carcinoma	Type 2	Direct communication
1373	69 M	Oesophageal cancer	Types 4 and 5	No anastomosis
1382	53 F	Non-small cell lung cancer	Type 1	No anastomosis
1409	83 M	Intracerebral haemorrhage, accidental fall	Type 2	Approaching communication
1413	88 F	Natural causes, hypertension	Type 5	Approaching
1427	81 M	Gastrointestinal bleed, bladder cancer, chronic renal failure, congestive heart failure, bilateral pleural effusion	Type 4	Direct communication
1428	86 F	Ischaemic heart disease, chronic heart failure, atrial fibrillation	Type 3	Approaching communication
1430	87 M	Pneumonia, stroke	Type 4	Approaching communication
1434	73 M	Heart failure, lung cancer, ischaemic heart disease, chronic obstructive pulmonary disease	Type 2	Approaching communication

vastus lateralis until their diminished size and integrity was deemed unsafe for further dissection. At this point, the inferior approach was commenced.

Inferior 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 lateral superior genicular artery were followed as they approached the territory of the terminal branches of the DBLCFA.

Analysis

Arteries offering a potential collateral circulation were dissected as far as possible (<0.5mm in diameter). The vessels were supported to prevent disruption and repaired if breakage occurred. When dissection was no longer possible, the block of tissue in which the vessel terminated was preserved.

Anastomoses were classified as 'direct', 'approaching' or 'no anastomosis'. A direct anastomosis was present if a single vessel was found to be continuous with branches of the CFA or SFA above and with branches of the popliteal artery below. An anastomosis was determined to be approaching if terminal branches from the femoral (CFA or SFA) and popliteal arteries could be dissected to a common block of tissue of 2cm x 2cm x 2cm. An anastomosis was thought to be unlikely and categorised as no anastomosis if arteries from the femoral (either CFA or SFA) and popliteal systems terminated in different blocks of tissue. Donor number, date, time and description were used to label all photographs.

Results

The average age of the dissected cadavers was 77.3 years (range: 53–88 years). Medical history was unknown except for the cause of death. The subjects' age, sex, cause of death and anatomic findings are given in Table 1. There was considerable variation in this relatively small sample but no correlation was evident between variables. Even though some of the subjects died of cardiovascular or cerebrovascular events, severe peripheral vascular disease was not seen in our subjects.

A long artery was found in each of the specimens to descend down the lateral aspect of the thigh toward the knee. It usually lay between the rectus femoris and vastus lateralis, supplying each muscle. This was the only candidate artery that could have bypassed an obstruction in the SFA.

The origin of this artery was variable and we categorised it into five arrangements based on its parent trunk (Fig 2). In Type 1 (2/10 limbs), the descending artery arose from the lateral circumflex branch of the femoral artery. In Type 2 (3/10 limbs), the pattern was similar to Type 1 except that the lateral circumflex femoral artery arose from the PFA. In Type 3 (1/10 limbs), Type 4 (3/10 limbs) and Type 5 (2/10 limbs), the descending artery arose directly from the CFA, SFA or PFA respectively. In one limb, there were two descending arteries: one arising from the PFA (Type 5) and one arising from the SFA (Type 4).

A direct arterial communication was seen between the terminal branch of the lateral descending artery of the thigh and a terminal branch of the lateral superior genicular artery was seen in three of ten limbs. In five limbs, the two arteries were clearly approaching each other with their terminal branches ending in the same block of muscle but a discernible communication was not seen. In the remaining

two limbs, communication was thought to be unlikely as the descending artery and the lateral superior genicular artery terminated in different blocks of tissue at some distance from each other. On the medial side of the knee, a branch of the SFA arose at Hunter's canal and terminated in small branches at the capsule of the knee.

Thus, our findings differed from the common understanding of this anatomy in two ways:

- > A branch of the femoral artery descends in the lateral aspect of the thigh but it rarely arises from the lateral circumflex femoral artery.
- > Robust direct communications between branches of the femoral and popliteal arteries do not exist.

Only a minority of subjects had a direct anastomosis between extremely small vessels, some had the potential for communication via capillaries and others had no possibility of communication. In all subjects, collateral flow was unlikely to be sufficient in the event of acute obstruction of a normal SFA.

Discussion

Henry Gray designed his textbook to be relevant to medical students and practising surgeons. Vandyke Carter's drawings of dissections made by Gray and Carter for the first edition of the textbook in 1858 contributed significantly to the enduring success of the textbook. In the second edition of 1860, Gray added a written description of the collateral circulation after ligation of the femoral artery, which he attributed to Sir Astley Cooper.⁵ Reading Cooper's original paper, it is clear that Cooper believed most patients would muster sufficient collateral flow, via the anastomoses of smaller vessels, to permit the surgeon to ligate any major artery in order to control aneurysms or hemorrhage.⁶ The observations that Gray quoted were made by Cooper when he performed an autopsy on a man whose SFA was ligated for a popliteal aneurysm seven years earlier.

After Gray's untimely death in 1861, the textbook's first editor Timothy Holmes added a reference to an anatomic specimen taken from a patient who lived 50 years after John Hunter ligated his femoral artery.⁷ This prosection was made by Thomas Wormald, the patient's last physician, and is still retained by the Hunterian Museum at The Royal College of Surgeons of England.^{8,9} Wormald presented the specimen to the College after giving a Hunterian oration on the topic in 1857, one year before Gray first published his textbook. Both Hunter's specimen and Cooper's description suggest the principal afferent vessel to be a descending branch of the PFA. Citation of Cooper's 1811 paper was maintained until 1949 while subsequent editions of *Gray's Anatomy* continued to use his description but without attribution.

The idealised illustration of the arterial anastomosis at the knee, which was added to early 20th century editions of *Gray's Anatomy*, was preceded in 1908 by a diagram attributed to Paul Poirier and Adrien Charpy, whose multivolume textbook was published in 1901.¹⁰ These illustrations are most likely based on the Hunter specimen and Cooper's

written description, both of which reflect pathological collateral circulation many years after ligation of an abnormal vessel. This potentially inaccurate idealisation continues to be considered today to represent normal anatomy. Current editions of *Gray's Anatomy* continue to publish the 1910 illustration but now without any link in the text.

Anatomical study of the arterial anatomy of the lower extremity was commenced again by Dr DeBakey and colleagues in 1960.¹¹ Subsequent studies used increasingly sophisticated angiography, with and without 3D imaging, mostly to document variation in the branching pattern of the popliteal artery, in particular to warn against harvesting a vascularised tissue graft based on the fibular artery in patients with a fibular dominant variant.^{12–15} None of these studies demonstrated collateral circulation via genicular anastomoses.^{11–15}

There is a good reason why we rely on occasional 200-year-old dissections of pathological circulation to define the normal arterial anatomy around the knee. It is still very difficult to demonstrate the genicular anastomosis, even in this technological age. CTA and MRA fail to show it because of preferential flow of contrast through the SFA in normal subjects. 3D reconstruction of anatomic cryosections do not have sufficient resolution to distinguish very small vessels, especially at branch points or when sliced tangentially. Traditional dissection remains the best method to demonstrate this anatomy, with high resolution photography being our only advantage over the golden age practitioners of surgical anatomy, whose dissection skills we may have lost.

While our ability to demonstrate the genicular anastomosis is limited, we were never hampered in our understanding of the DBLCFA. Textbooks show this artery invariably to be a branch of the lateral circumflex femoral artery, which arises from the PFA. We only found this arrangement in four of the ten limbs dissected. The 'descending branch of the lateral circumflex femoral artery', the name given to this arrangement, is unsuitable for the other variants as it may mislead the surgeon. Variation in the arterial anatomy at this location has been demonstrated previously using radiological techniques but the findings have not found their way into surgical atlases.^{16,17} Our small sample and these studies suggest that only a minority of subjects have the classical arrangement of the DBLCFA. Consequently, we suggest renaming the DBLCFA to the more anatomically correct 'lateral descending artery of the thigh' (LDAT).

The contribution of the LDAT to a genicular anastomosis is also variable. It appears to be present or potentially present in about 70% of patients. Removal of this potential for collateral circulation may have significant consequences if the SFA is already (or becomes) occluded. Acute distal limb ischaemia following anterolateral thigh free flap harvest has been reported.¹⁸ On the other hand, the calibre of communicating vessels, when they are seen, is never sufficient to preserve blood flow to the lower leg in the event of acute disruption of a normal SFA. Sir Astley Cooper described distal ischaemia requiring amputation following ligation of the SFA for a popliteal aneurysm in his 1811 paper but he blamed cold weather.⁶ Most likely, gradual obstruction of the SFA by atherosclerosis permits recruitment of

collateral circulation in those patients fortunate enough to have a genicular arterial anastomosis.

Conclusions

The initial hope of the research reported here was to determine whether non-surgical options might exist for soldiers who sustain SFA injuries in combat. Our finding that a third of subjects do not have a potential for collateral circulation at the knee makes that hope less likely. The study group is much older than the population at risk. There is a chance that we could mistake collateral circulation, developed at a later age in response to occult peripheral vascular disease, for anatomical anastomoses and overestimate the number present. Our inability to demonstrate the anastomosis is therefore even more convincing of its absence in a substantial portion of the population.

Acknowledgement

The material in this paper was presented in part at the annual meeting of the American Association of Anatomists held in Anaheim, CA, in April 2010.

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