The effect of knee flexion on the popliteal artery and its surgical significance

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Total knee replacement and high tibial osteotomy are common orthopaedic operations with low complication rates. Such surgery is in close proximity to the popliteal artery (PA), the behaviour of which during flexion of the knee is poorly understood.

We used Duplex ultrasonography to determine the distance of the PA from the posterior tibial surface at 0˚ and 90˚ of flexion in 100 knees. When the knee was flexed the PA was closer to the posterior tibial surface at 1 to 1.5 cm below the joint line in 24% and at 1.5 to 2 cm below the joint line in 15%. There was a high branching anterior tibial artery in 6% of knees. We provide an anatomical account to help to explain our findings by using cadaver dissections, arteriography and static MRI studies.

Received 22 May 2003; Accepted 27 June 2002

Total knee replacement (TKR) and high tibial osteotomy (HTO) are common orthopaedic operations. Both are normally performed with the knee in 90˚ of flexion and require a transverse tibial cut 1 to 2 cm distal to the posterior tibial joint line. This is close to the popliteal artery (PA) which may be injured, although this is rare with an overall incidence during TKR of 0.12%.1 There are only a few reported instances of direct injury to the PA during HTO.2-4 Transection, traumatic aneurysm, thrombosis, fistula and rupture of atherosclerotic plaques are all described.

There are conflicting theories as to the movement of the PA during flexion of the knee. In 1932, Curtillet and Seror5 studied cadaver dissections and arteriograms. They concluded that it moved away from the tibia as the knee was flexed. Three years later, Van Hayek6 noticed during radiological flexion studies of living feline knees that the PA moved away from the joint capsule during flexion. In 1973, Coventry7 suggested that HTO should be performed with the knee flexed in order to place the PA away from the joint capsule thus obviating injury. Vernon et al8 used angiography on cadaver knees and demonstrated that the PA moved posteriorly during flexion, perhaps because of uncoiling of the spring-like middle genicular artery during flexion. A recent in vivo axial MRI study9 of nine knees showed that the PA became displaced posteriorly during flexion of the knee due to morphological changes in the structures within the popliteal fossa. In 1995, Zaidi et al4 studied the in vivo cross-sectional behaviour of the PA in 20 knees using Duplex ultrasonography at the level at which HTO is performed. In 12 knees (60%) the PA moved closer to the tibia at 90˚ of flexion.

Most of these studies have been done on only a few subjects or on stiff cadaver specimens. We have performed an in vivo study of the PA in 100 knees using colour flow Doppler ultrasonography. We measured its distance from the posterior tibial surface during flexion and extension at 1 to 1.5 cm and 1.5 to 2 cm distal to the posterior tibial joint line. These two levels were chosen since they correspond to the levels at which TKR and HTO are respectively performed.

Patients and Methods

We used an Aloka 2000 coloured Duplex machine to study 100 knees in 50 patients (25 men and 25 women) who had been admitted for other, unrelated treatments at the hospital. Their mean age was 56.4 years (21 to 96). None of the knees had had previous surgery and all were clinically stable when examined. The patients were examined in the supine position to allow for the gravity effect on the PA, as would be the case during TKR or HTO. Using a 5 MHz
linear array probe, the PA and the posterior tibial cortex were visualised in the sagittal plane within the popliteal fossa. Using colour flow imaging, the distance between the posterior tibial cortex and the anterior aspect of the PA was measured. This distance was termed the ‘bone-to-artery’ distance (BAD). Measurements were made at 1 to 1.5 cm and 1.5 to 2 cm distal to the posterior articular surface of the tibia. Each measurement, at each level, was performed first with the knee in full extension and then at 90˚ of flexion. The same, experienced observer (KWKF) performed these measurements throughout the study in order to reduce inter-observation bias.

Cadaver dissections of the popliteal fossa were also performed to help in the understanding of the anatomy of the tibial portion of the PA and structures influencing the movement of this vessel.

The behaviour of the PA was studied in the sagittal and axial planes by using in vivo MRI. This was compared with the ultrasound findings. T1-weighted echo scans were made of the knee in both full extension and 90˚ of knee flexion. The BAD was determined in both the axial and sagittal planes at the two chosen levels of surgery and the results were analysed using a z-test. Finally, we studied an arteriogram, taken in flexion and extension, of the lower limb of one patient who was undergoing arteriography as an investigation for arterial insufficiency.

**Results**

The change in the BAD varied in the 100 knees studied. The overall trend was, however, for the PA to move away from the posterior tibial cortex at both levels studied. At the level of TKR (1 to 1.5 cm distal to the posterior tibial articular surface) the BAD varied from a mean of 5.9 mm (2.6 to 14.5) in full extension to 7.2 mm (1.8 to 12.3) at 90˚ of flexion. In 76% of the knees the PA moved away from the posterior tibial surface during flexion of the knee (Fig. 1). The mean change in BAD from extension to 90˚ of flexion was 1.4 mm (-5.8 to +6.5). This was statistically significant (z-test, p < 0.01). At the level of HTO (1.5 to 2 cm distal to the posterior tibial articular surface) the BAD varied from a mean of 8.6 mm (4.6 to 19) in full extension to 10.2 mm (4.6 to 17.3) at 90˚ of flexion. In 85% of the knees the PA moved away from the posterior tibial surface during flexion of the knee (Fig. 1). The mean change in BAD from extension to 90˚ of flexion was 1.7 mm (-9 to +6). This was also statistically significant (z-test, p < 0.01). In the remainder of the cases, the artery moved towards the tibia (Fig. 2). In six knees (one
patient with bilateral involvement) a high-branching anterior tibial artery arose from the PA, proximal to the popliteus muscle. In all six knees it passed anterior to the popliteus and was therefore directly related to the posterior tibial surface (Fig. 3). It moved away from the posterior surface of the tibia in 90° of flexion.

Cadaver dissection showed that the tibial portion of the PA is fixed between the middle genicular and lateral inferior genicular vessels. The middle genicular vessel was invariably a coiled structure which passed through the oblique popliteal ligament and into the posterior aspect of the capsule. The lateral inferior genicular vessel was closely related to the popliteus muscle.

The sagittal and axial MR images of the knee showed a similar pattern of posterior displacement of the PA from the posterior tibial surface in 90° of flexion at both levels. This was associated with an increase in the bulk of the popliteus muscle (Fig. 4).

The arteriogram showed the artery to be fixed both at the adductor hiatus and at the bifurcation. During flexion, the tibial portion of the artery slid proximally and the excess length formed coils posterior to the femur. Angiography also showed the presence of many sural vessels, which may exert a posterior pull on the PA as the knee is flexed (Fig. 5).

Discussion

TKR and HTO are common procedures which are performed close to the PA. A direct injury of the artery can be catastrophic for the limb. Rubash et al11 found that even during screw fixation of a tibial prosthesis there was the potential for vascular injury. Such injuries are fortunately rare in TKR and even rarer for HTO.

The PA traverses the popliteal fossa from the opening of the adductor magnus and then descends laterally to the intercondylar fossa, inclining obliquely to the distal border of the popliteus. Here it divides into the anterior and posterior tibial arteries. The anterior relations to the PA proximodistally are fat covering the femoral popliteal surface, then the capsule of the knee, and finally the fascia of popliteus.12 The popliteus muscle has a flat and triangular-
shaped belly with a tendinous attachment to the lateral femoral condyle. This then broadens to attach to the posteromedial aspect of the tibia, proximal to the soleal line. It forms the floor of the popliteal fossa and has a fascial covering which is mostly derived as an expansion of the tendon of semimembranosus. The distal portion of the PA is separated from the posterior tibial surface by the popliteus muscle and is barely protected from potential injury at this level during TKR and HTO. Normal division of the PA into the anterior and posterior tibial arteries occurs at the lower border of the popliteus muscle.

The question as to whether the PA is in a safer position at 90˚ of flexion during routine operations such as TKR and HTO remains unanswered. Many papers describe the pattern of behaviour of the PA during knee flexion. Studies vary from anatomical dissections to in vivo analyses using angiography and MRI. Most authors have concluded that the PA moves away from the posterior aspect of the tibia during flexion of the knee although these studies have been performed on cadaver specimens. They are a poor substitute for in vivo investigations. Unfortunately, most in vivo analyses in this field have involved only a few subjects. Smith et al studied the behaviour of the PA in nine subjects by using MRI and found that the popliteal vessels moved away from the posterior surface of the tibia at 90˚ of flexion. Zaidi et al did describe a posterior displacement of the PA in one flexed knee by using MRI, but were only able to achieve 20˚ of flexion because of the dimensions of the MR coil. In our MRI study the BAD increased at 90˚ of knee flexion at the two levels in both the sagittal and axial planes. This confirms the findings of Smith et al.

Previous cadaver experiments have found that the distal aspect of the PA is relatively fixed at the origin of the anterior tibial artery and at a more proximal point which corresponds to the origin of the descending genicular artery. Posterior movement of the PA between these two fixed points does occur during flexion, with the creation of flexures behind the posterior articular structures of the knee. In our cadaver dissections of the popliteal fossa we found a tibial segment of the PA to be fixed at two points (the middle and lateral inferior genicular vessels) in the area for the two levels of surgery. Further dissection revealed that the middle genicular vessels were coiled. In angiographic studies performed on cadaver knees the middle genicular vessel progressively uncoils until it becomes straight during flexion of the knee. This displaces the tibial portion of the PA posteriorly, and may help to explain the small amount of movement of the PA seen in our Doppler images. Study of the arteriograms confirmed these cadaver findings in vivo. We also found that the lateral inferior genicular vessel was closely related to the popliteus muscle. MRI of the
flexed knee showed an increase in the axial cross-sectional area of the popliteus muscle when compared with the extended knee. This may also contribute to the posterior displacement of the PA within this area. However, we only studied one knee and the bulk of the popliteus muscle is likely to vary among individuals.

We have shown that flexion may be considered to be a safer position for surgery on the knee in the supine position. However, when considering the two levels of knee surgery, the PA still moved towards the posterior tibial surface in 15% and 24%, respectively, at 90° of flexion. Therefore, the flexed knee does not always confer safety. An understanding of the variations in the branches of the PA also has significant implications for surgery since we have also demonstrated an incidence of a high branching anterior tibial artery of 6%. These branches have an extremely close relationship to the posterior tibial surface. It is important that the surgeon should still exercise extreme caution during the placement of retractors, and with the use of oscillating saws and osteotomes, in this region during surgery on the knee.

We thank Professor Harold Ellis, CBE, MCh, FRCS of the Department of Anatomy at Guy’s Hospital for help in the preparation of this paper and John Foulkes of The Royal College of Surgeons for help with the statistical analysis.

No benefits have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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