Arterial Supply to the Human Anterior Cruciate Ligament

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ABSTRACT: The arterial supply to the anterior cruciate ligament (ACL) was prepared for study by injecting a fresh cadaver knee with an epoxy lead-oxide solution and subsequently immersing it in 10% formalin for a 2-week period. The vascularity of the ACL was exposed through dissection for examination. A second specimen was prepared similarly and was evaluated by a CAT scan. ACL vascularization arises from the middle genicular artery and vessels of the infrapatellar fat pad and adjacent synovium. The artery gives rise to periligamentous vessels which form a web-like network within the synovial membrane. These periligamentous vessels give rise to penetrating branches which transversely cross the ACL and anastomose with a network of longitudinally oriented endoligamentous vessels. Terminal branches of the inferior medial and lateral genicular arteries supply the distal portion of the ACL directly. The extremities of the ACL seem to be better vascularized than the middle part, and the proximal portion seems to have a greater vascular density than the distal portion. The arteries at the ligamentous-osseous junctions of the ACL do not significantly contribute to the ligament’s vascularity. Ramifications concerning the ACL’s blood supply as it relates to athletic training is also discussed.

Scientific literature concerning the functional anatomy, recognition, treatment, and rehabilitation of the injured anterior cruciate ligament (ACL) of the knee is plentiful, however, information regarding this ligament’s vascularization is lacking. Dunlap et al8 claim that the vascular pattern of the ACL is not well understood and state that few studies have attempted to quantify the vascular perfusion of the ACL. The vascular anatomy described in humans has been shown to be comparable to that in canines; thus, much of the original research to date concerning the blood supply to this ligament has been performed on dogs. Few studies of ACL vascularization have been performed on human cadaver specimens. The ACL has been described as a relatively hypovascular structure. However, some researchers have claimed that there are adequate intraligamentous blood vessels throughout the entire ligament for healing to occur following injury. Disruption of the ligament’s blood supply has been described as the cause of the profuse effusion and hemarthrosis experienced 24 hours after initial injury. DeHaven reported that of 113 acute knee injuries associated with hemarthrosis incurred within 4 hours of trauma, 81 (72%) were caused by injury to the ACL.

Gaining an understanding of the source of effusion may aid the athletic trainer in evaluating, treating, and rehabilitating injuries to the ACL. In addition, the athletic trainer may be able to use this information to enhance an athlete’s adherence to an injured ACL’s treatment and subsequent rehabilitation program. A proper understanding of the arterial supply of the ACL will allow the athletic trainer to better respond to an athlete’s questions about the large amounts of hemorrhosis the athlete will experience in an ACL injury.

METHODS

In order to display the arterial pattern of the human ACL, the arteries of two fresh cadaver knees were injected with an epoxy solution containing lead oxide. The lead oxide was added to the epoxy to highlight the specimen’s vascular network and to add density for Computer Axial Tomography (CAT) scan analysis. The epoxy solution was allowed to dry and harden. Then, the specimens were immersed in a 10% formalin solution for 2 weeks. Subsequently, all soft tissue superficial to the ACL of one specimen was discarded and the vascularature of the ligament, which was now easily identified by the bright orange coloration, was examined through fine dissection. After being removed from the formalin solution, the unaltered second specimen was subjected to a CAT scan and the ligament’s vascularity was studied. It should be noted that since only two specimens were used in this study, the reported results may not be indicative of the arterial patterns exhibited by the average ACL. As a result, the conclusions drawn may not be representative of the general population.

RESULTS

Anterior cruciate ligament vascularization arose primarily from the middle genicular artery and the adjacent synovium. After branching from the popliteal artery, the middle genicular artery coursed along the dorsal aspect of the ACL while giving rise to ligamentous branches to the ligament (Fig 1). These ligamentous branches seemed to form a network of vessels, which gave rise to connecting branches that transversely crossed the ACL and anastomosed with longitudinally oriented intraligamentous vessels (Fig 2). The transverse branches

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connected to the intraligamentous vessels primarily at the ligament's proximal and distal ends. The arteries entering the proximal part of the ligament were larger than the arteries entering the distal part.

In addition to supplying the ACL, the middle genicular artery was responsible for providing blood supply to the distal femoral epiphysis and proximal tibial epiphysis. The middle genicular artery ultimately bifurcated into right and left arteries at a point just proximal to the tibial spine. These arteries were then distributed to the right and left tibial condyles, respectively (Fig 1).

Additional blood supply to the ACL came from the inferior medial and lateral genicular arteries. These arteries branched from the posterior surface of the popliteal artery before traversing anteriorly. The inferior medial genicular artery passed below the medial condyle of the tibia and deep to the tibial collateral ligament, while the inferior lateral genicular artery passed proximal to the fibular head and deep to the fibula collateral ligament. The inferior lateral genicular artery ran at the level of the joint line and was found to provide vascularization to the periphery of the lateral meniscus as it passed (Fig 3). These arteries eventually became embedded and anastomosed within the infrapatella fat pad located on the posterior surface of the patella ligament (Figs 3 and 4). Terminal branches of the inferior genicular arteries supplied the distal portion of the ACL directly (Fig 3).

DISCUSSION

Our findings substantiate the work of others who reported the vascularization of the ACL to be predominantly of soft tissue origin.1,5,22

Middle Genicular Artery Supplying the Anterior Cruciate Ligament

The majority of the ligament's blood supply originates from branches of the middle genicular artery and the adjacent synovium.1,3,5,14,22 The middle genicular artery penetrates the posterior joint capsule at the level of the intercondyloid notch,22 and courses within a synovial membrane which surrounds the ligament.1,5,22 This synovial membrane originates at the posterior inlet of the intercondylar notch of the femur and extends around the proximal attachment of the ligament.1 Scapinelli22 referred to the portion of the middle
genicular artery coursing along the dorsal aspect of the ACL as the “tibial descending branch” of the middle genicular artery (Fig 1).

The ligamentous branches arising from the middle genicular artery that give rise to transversely orientated connecting vessels have been described as a web-like network of periligamentous vessels.\(^1,4,5\) within the synovial membrane.\(^1,4,5\) which ensheaths the entire length of the ligament.\(^1,4\) Our findings related to these periligamentous vessels agrees with the work of others.\(^1,4,5,14,15\) Many have termed these intraligamentous vessels “endoligamentous” vessels (Fig 2).\(^1,4,15\) Kennedy et al\(^14\) described them as tortuous in nature, thus enabling them to withstand the demands of the ligament’s complex movements.

The central portion of the ACL is less vascular than its proximal and distal portions.\(^1,5\) Histological sectioning has demonstrated that the number and size of vessels in the central portion of the ligament are less than the ligament’s proximal and distal portions.\(^1\) We agree with the assertion that the transverse branches arising from the periligamentous vessels connect to the endoligamentous vessels primarily at the ligament’s proximal and distal ends. The extremities of the ACL seem to be better vascularized than the middle part. Our observation that the arteries entering the proximal part of the ligament were larger than the arteries entering the distal part agrees with the work of Alm et al.\(^1\) We agree that the proximal portion of the ACL has a greater vascular density than the distal portion.

**Middle Genicular Artery Supplying the Anterior Cruciate Ligament’s Ligamentous-Osseous Junctions**

In addition to supplying the ACL, the middle genicular artery is responsible for the majority of the blood supply to the distal femoral epiphysis and proximal tibial epiphysis.\(^22\) However, arteries at the ligamentous-osseous junctions of the ACL do not significantly contribute to the ligament’s vascularity.\(^5,15,22\) This avascularity is a general feature of all ligamentous attachments and corresponds histologically to a layer of fibro cartilage.\(^22\) The arteries that bifurcate at the distal end of the tibial descending branch of the middle genicular artery have been referred to as right and left “tibial condylar” arteries (Fig 1).\(^22\)

**Medial and Lateral Inferior Genicular Arteries Supplying the Anterior Cruciate Ligament**

The course of both inferior medial and lateral genicular arteries in our specimens mimicked the findings of others.\(^3–5,8\) that additional blood supply to the ACL comes from the infrapatella fat pad via the terminal branches of these arteries. The inferior lateral genicular artery may aid in the formation of the membrane’s weblike network by connecting with periligamentous vessels.\(^4\) Our observation that the lateral inferior genicular artery provides vascularization to the periphery of the lateral meniscus supports the work of Scapinelli.\(^22\)
Implications for Athletic Training

Educating athletes about their particular injury is an important initial step in the rehabilitation process. Thus, athletic trainers need to demonstrate their competence to help reassure the injured athlete that they have the knowledge to deal with his/her particular condition. Although this will not guarantee that the athlete will adhere better to their treatment program, athletic trainers feel that explaining the injury to the athlete plays an important role in getting the athlete to comply with the rehabilitation process. Too little information provided to some individuals may cause limited treatment adherence; therefore, these athletes need to understand the nature and the extent of their injuries more than others. Although athletes seem to place more emphasis on knowledge of the rehabilitation regime than on the details of the injury, not all athletes will be uninterested in the details of their injuries.

The athletic trainer should also appreciate how injury to certain structures affects the arterial supply to the ACL. Intact synovial tissue and an intact infrapatella fat pad contribute to the vascularity of the ACL. Thus, injury to these structures greatly diminishes the ACL vascularization in the canine model. Dissection of the ligament’s surrounding synovium almost completely disrupts blood flow to the ligament. Division of the infrapatella fat pad causes a twofold decrease in perfusion to the ACL. Hemorrhagic effusion as a result of injury to the ACL almost always involves lesions to the branches of the middle genicular artery. Therefore, disruption of these soft tissues accounts for the profuse effusion and hemorrhiosis experienced following initial injury to this ligament. Scapinelli claimed the avascular nature of the insertions of the ACL ligament to its bony attachments explains the slowness of the repair process after traumatic detachments at this level.

During the rehabilitation of a nonsurgical tear of the ACL, the athletic trainer should realize that anterior stresses on the ligament’s arterial supply will diminish the blood flow to the ligament in canine specimens to one-fifth of baseline value. Blood flow returns to normal, however, after cessation of the stress. Return of perfusion is important to the maintenance of the ACL over prolonged periods. Dunlap et al have suggested that the ligament may experience periods of increased blood flow followed by decreased blood flow during exercise. This event may play a role in those cases when the ACL becomes injured during excessive anterior displacement of the tibia on the femur. Although the benefits of early passive motion of a joint following the trauma of surgery are reported in the literature, the use of continuous passive motion on the knee joint following ACL surgery does not increase nutrient uptake.

REFERENCES