Mechanoreceptors of the Posterior Cruciate Ligament

PK ATONIS 1, A PAPOUTSIDAKIS 1, A ALIGIZAKIS 1, G TZANAKAKIS 2, GM KONTAKIS 1 AND PJ PAPAGELOPOULOS 3

1Department of Orthopaedics and Traumatology, and 2Department of Histology, Medical School, University of Crete, Heraklion, Greece; 3First Department of Orthopaedics, Athens University Medical School, Athens, Greece

The mechanical role of the anterior and posterior cruciate ligaments in the passive and functional stability of the knee joint has been well documented. Both these knee joint ligaments contain Ruffini, Pacinian, Golgi and free nerve endings with different capabilities of providing the central nervous system with information regarding movement and position as well as chemical events. The posterior cruciate ligament provides 95% of the restraining force to a posterior tibial displacement, is significantly stronger than the other knee ligaments, and sensory nerve endings are located in the tibia and femoral bone insertions. This report aims to review the anatomy and physiology of the various mechanoreceptors of the posterior cruciate ligament, placing special emphasis on their role in knee joint stability. It concludes that the posterior crude ligament may not only serve as a ‘mechanical stabilizer’ of the knee joint, but also probably has an important ‘sensory function’ that should be taken into account when dealing with injuries to it.

KEY WORDS: POSTERIOR CRUCIATE LIGAMENT; KNEE; MECHANORECEPTORS

Introduction

For the last 20 years orthopaedic surgeons have been interested in the cruciate ligaments, not only as mechanical and structural stabilizers of the knee joint, but also as sensory structures. The proprioceptive roles of the anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) have been investigated further because of the increasing number of reconstruction surgeries performed, such as total knee arthroplasty and arthroscopic ligament reconstruction. Specifically, the PCL intraligamentous neural network, which is responsible for neurosensory function, has been widely investigated in animals and humans.

This current review focuses on the anatomy and physiology of the various mechanoreceptors of the PCL, placing special emphasis on their role in knee joint stability.

Methodology

The methodology included a thorough literature search. The Entrez PubMed database (http://www.ncbi.nlm.nih.gov) for the years 1966 – 2005 was queried for the terms posterior, cruciate, ligament, knee, sensorimotor control, sensory, proprioception, receptors, mechanoreceptors in all their possible combinations. For example the
sought terms ‘posterior cruciate proprioception’, ‘posterior cruciate sensorimotor control’, ‘posterior cruciate mechanoreceptors’ and ‘posterior cruciate sensory receptors’ resulted in 14, zero, 12 and eight references, respectively. All the available English literature was reviewed, as well as any available references cited within that literature. If the native language of a report was not English, data were collected from the abstract or from a translation of the report if that was available.

History
Since 1944 when Gardner1 studied the distribution and termination of nerves in the knee joint of the cat, many authors have shown an increased interest in the knee neurosensory hypothesis. Especially, the mechanoreceptors of the PCL have been widely studied in animals,2 arthritic knees3 and cadaver human knee joints.4

Knee joint stability
The role of the knee is to allow flexion–extension motion, and this occurs through a combination of the femur rolling and gliding on the tibia. With rolling alone, the femoral condyle would roll off the tibial plateau before maximum flexion was achieved, whereas with gliding alone the femoral shaft would impinge on the tibia.5 Combined rolling and gliding allows full flexion at the knee and the cruciate ligaments guide this knee motion. The ACL and PCL are arranged in a crossed configuration, with their attachments to the tibia and femur located in order to guide the femur as it moves on the tibia.

Passive joint stability
The ligaments and the menisci provide restraints to the relative translations of the femur with respect to the tibia, while allowing functional rotations. For medial opening of the joint the medial collateral ligament (MCL) has been shown to provide approximately 57% of the restraining moment, with approximately 15% from the ACL and 25% from the joint capsule at 5° of knee flexion; but at 25° of knee flexion this increases to 78% for the MCL.5 A similar distribution occurs for the lateral collateral ligament (LCL) under a moment opening the lateral side of the joint. With internal rotation of the tibia with respect to the femur, the MCL and the LCL together contribute approximately 40% of the resisting moment, whereas the PCL and the posterior capsule contribute less.5 Posterior translation is resisted primarily by the PCL. With the posterolateral structures sectioned (popliteus tendon, LCL, posterolateral capsule), there is little increase in posterior translation as long as the PCL is intact. Anterior translation of the tibia is prevented passively by the ACL.

Functional joint stability
The muscles around the knee are the active stabilizers of the joint. Muscle activation reduces the laxity zone, or the region where very little force is required to create rotatory motion, and also increases the stiffness of the joint in all regions. The knee flexor and extensor muscles also demonstrate a pattern of coactivation. The coactivation of both quadriceps and hamstrings stabilizes the joint further against anterior and lateral translation and rotation. In a similar manner, the popliteus muscle has been shown to decrease the force in the PCL under a posteriorly directed load.5

Anatomy, biomechanics and receptors in the PCL
Symptoms of instability in the knee joint after PCL injury are commonly attributed
solely to loss of passive mechanical restraint, which is normally provided by intact ligaments. The normal ligament contains receptors that initiate a more active mechanism of protective joint restraint, a process that ceases with the interruption of afferent impulses from the ligaments.5

Reconstruction of the PCL, however, does not involve simple passive reconstruction of the ligament. A new graft does not have the receptors of the previous ligament so proprioception has to be replaced by other knee structures. It is very important that this is taken into account by those involved in rehabilitation programmes for patients who have undergone PCL reconstruction. It is interesting that much research has been carried out on ACL receptors and proprioception, but very few articles have been published in this area on the PCL. This may be as a result of the greater prevalence of ACL ruptures compared with PCL ruptures.5

In 1995, Franchi et al.6 in their histological study using PCLs removed from osteoarthritic and normal knees found that the PCL has a neural network and that mechanoreceptors occupy 1% of the total area of the ligament. These mechanoreceptors were Ruffini endings, Ruffini corpuscles of the Golgi tendon organ-like type and Pacinian corpuscles. The complex population of mechanoreceptors of cruciate ligaments provides the central nervous system with information on the movement and position of the joint. Their study concluded with the proposal that loss of mechanoreceptors is part of the degenerative changes that affect the PCL in osteoarthritic disease.

In a guest editorial in 1996, Gillquist2 underlined the importance of the role of the cruciate ligaments in knee proprioception. He attributed failure of cruciate ligament reconstruction to failure in restoration of the nerve supply and proprioception function. He also noted the possibility for interaction to occur between sensory feedback and the activity of the quadriceps and hamstrings.

Several studies have looked at the functional role of the ligaments.2,3,7–11 In 2002, in a study on the spinal effects of ligament activity, the authors found that, in general, ligaments around the joints contain mechanosensitive nerve endings that are involved in providing the central nervous system with information about joint positions and movement.9 Afferents emanating from joint mechanoreceptors have been shown to project to spinal motoneurons and interneurons, as well as to a number of supraspinal structures.9 In addition to sensory properties, the ligaments have a mechanical role by restraining hyperrotation of the joint. Another study by the same authors found that the effects on the γ-muscle spindle system in the muscles around the knee are so potent that even stretching of the cruciate ligaments at relatively moderate loads (not noxious) may induce major changes in the responses of the muscle spindle afferents.10 Since afferents originating in ligaments are involved in the control of muscle stiffness and co-ordination, Johansson et al.8 concluded that ligaments contribute to functional joint stability by a combination of their mechanical and sensory characteristics. It was assumed that, when a joint approached the limit of its normal working range, high threshold mechanoreceptors in the capsule and ligaments prevent damaging hyperrotations by activating fast reflex pathways to the surrounding muscles. In referring to the excellent results obtained for treating ACL tears using primary repair augmented with a tendon graft, and considering that the proximal and distal ends of the cruciate ligaments are densely equipped with sensory
Posterior cruciate ligament mechanoreceptors

In 1991, Katonis et al. in their histological study on cadaver human knees described two types of encapsulated mechanoreceptors. They were located at the femoral and tibial attachments and on the surface of the ligament. The types of nerve endings were: Ruffini corpuscles, Vater-Pacini (Pacinian) corpuscles and free nerve endings. The Ruffini corpuscles consisted of a loose arborization of nerve fibres ending in flattened expansions and interspersed with a granular material dotted with nuclei (Fig. 1). Elongated connective tissue bundles and fibroblasts provided support to the structure. The Vater-Pacini (Pacinian) corpuscles were made up of a central elongated granular mass with many concentric thin layers (Fig. 2). The free nerve endings represented unmyelinated thin fibres. Another finding was the presence of capillaries surrounding all the different types of neural tissue (Fig. 3) and this led the authors to suggest that the free nerve endings may have a vasomotor action. They concluded that a rupture of the ligament would not only create a mechanical disturbance, but also a neurological disturbance caused by interruption of the afferent flow of nerve impulses to the central nervous system.

In 1998, Raunest et al. in their study of an adult sheep model identified three neural structures: Ruffini endings, Ruffini corpuscles of the Golgi tendon organ-like type and Pacinian corpuscles. They also identified free nerve endings. In their discussion they analysed the functional role of these neural structures. Pacinian corpuscles, which were the most common receptor population in the ligament, adapt rapidly and register any movement of the joint regardless of joint position, with the frequency of discharge being a function of the speed of movement. They have a very low threshold at the beginning and end of a movement. In
FIGURE 2: Vater-Pacini (Pacinian) corpuscles (large arrow); free nerve ending (small arrow) in the posterior cruciate ligament of a cadaver human knee (original magnification ×600).

FIGURE 3: Interfascicular connective tissue showing Vater-Pacini (Pacinian) corpuscles (large arrow) and surrounding capillaries (small arrows) in the posterior cruciate ligament of a cadaver human knee (original magnification ×40).
contrast, Ruffini endings are slow-adapting, respond to slight changes in ligament tension, have a capability for prolonged discharge, low threshold and serve to register joint position. Ruffini corpuscles (or the pilo-Ruffini complex A) were identified as a second subtype of the Ruffini mechanoreceptors.

In 1984, Schultz et al.3 in a histological study of PCLs removed from knees, found a few thin single unmyelinated axons at the PCL surface. The PCL was found to contain fusiform corpuscles, each consisting of a single axon wrapped in a fibrous capsule of one to three lamellae. The axons had terminal branches within the space defined by the capsule, but exited from it as a single process and joined larger nerve bundles a short distance away. The corpuscles were morphologically similar to Golgi tendon organs. These receptor organs lay on the surface of the PCL amidst fibrous fatty and vascular tissue, well beneath the external synovial sheath. A weak point of this study is that they used ligaments from knees with severe, end-stage arthritis, which is possibly why they found only one type of mechanoreceptor.

In 2001, Solomonow et al.13 in a review article on sensorimotor control of knee stability described the same receptors as the previous study but, in addition, they described the location of the receptors. The highest concentration was found at the insertion points where the ligament is stiffer and prevents constant overshooting during normal movement. The location of the receptors was also discussed in the article by Raunest et al.14 in 1996.

The mechanoreceptors in the PCL and their role in proprioception and knee function have been thoroughly described. Our literature review found both in vitro and in vivo studies on the function of the PCL. It is clear from all the studies we reviewed that the PCL is a very important ligament, with a significant number of mechanoreceptors that communicate with the central nervous system. The mechanoreceptors send messages according to the position and function of the knee joint, which is why the surrounding muscles become atrophic when the ligament ruptures. It is, therefore, vitally important that, during ligament reconstruction, the two ligament ends are restored as much as possible because that is where the mechanoreceptors are located; hence, it may be preferable to repair and augment the ligament rather than replace it with a graft. Rehabilitation programmes after a ligament rupture or reconstruction should also be planned in such a manner as to restore proprioception of the joint.

Conclusion
In conclusion, this review clearly indicates that the PCL may not only serve as a ‘mechanical stabilizer’ of the knee joint, but also probably has an important ‘sensory function’ that should be taken into account when dealing with injuries to it.

Conflicts of interest
The authors had no conflicts of interest to declare in relation to this article.

References


Author’s address for correspondence

**Dr Panayiotis J Papagelopoulos**

Athens University Medical School, 4 Christovassili Street, 15451 Neo Psychikon, Athens, Greece.

E-mail: pjp@hol.gr