Sonographic Evaluation of the Posterior Cruciate Ligament in Amputated Specimens and Normal Subjects

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The purpose of this study was to define the sono-graphic appearance and echogenicity of the normal posterior cruciate ligament. We examined the posterior cruciate ligament of five amputated specimens and five normal subjects using a 10 MHz linear array transducer. One K-wire was inserted into the substance of the posterior cruciate ligament of the amputated knee specimens to verify the location of the ligament on the sonogram. Various angles of insonation were used to examine the echogenicity of the posterior cruciate ligament. The results showed that the in situ posterior cruciate ligament appeared as a hypoechoic band relative to the surrounding tissue on sonograms, but it appeared hyperechoic when it was isolated and immersed in a water bath. The specific spatial orientation of the posterior cruciate ligament and anisotropy phenomenon contributed to the hypo-echogenicity of the posterior cruciate ligament in situ on sonogram. KEY WORDS: Posterior cruciate ligament; Knee, ligaments; Ligament, posterior cruciate; Sonography; Echogenicity; Anisotrophy.

Posterior cruciate ligament injuries occur in roughly 20 to 40% of cases of acute knee injury.1,2 Although arthroscopy can reliably define the pathologic features of the PCL, its clinical application is limited by its invasiveness and potential complications.3 MR imaging is believed to be the most reliable noninvasive method to detect the existence and extent of PCL injuries.4,5 However, MR imaging is expensive and is not universally available. In recent years, ultrasonography has been playing an important role in the evaluation of musculoskeletal disorders.6–11 It is noninvasive, is rapidly performed, provides real-time images, is widely available, is readily accepted by the patients, does not require ionizing radiation, and is relatively inexpensive in comparison to MR imaging.

The sonographic appearance of the PCL had been shown both in cadavers12 and in vivo.13,14 As the echogenicity of ligaments is an important parameter in the ultrasonographic diagnosis, knowledge of the normal echogenicity of the PCL is crucial. However, previous reports yielded conflicting information as they described the PCL as either hypoechoic15–18 or hyperechoic13,14,18 in comparison to the surrounding tissue.

ABBREVIATIONS

PCL, Posterior cruciate ligament; MR, Magnetic resonance

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tissues. To define the pattern of echogenicity of the PCL, we evaluated the ligament either in situ or as an isolated structure. The phenomenon of anisotropy in scanning the PCL and methods to obtain an optimal image of the PCL also were explored.

**MATERIALS AND METHODS**

Five fresh-frozen amputated knees from four men (aged 65 to 85 years) with peripheral vascular disease were used. None of the persons had a history of knee trauma and no gross pathologic findings were noted in the specimens. The frozen specimens were thawed before examination. A 10 MHz linear array transducer (ATL HDI3000, Advanced Technology Laboratories, Bothell, WA) was used to image the knees. The posterior sagittal approach from the popliteal fossa with the knee fully extended was used to obtain a longitudinal image of the PCL. The ultrasound transducer was placed between the lateral margin of the medial femoral condyle and the intercondylar area of the posterior end of the tibia and then rotated medially in the coronal plane to attain the best image of the PCL (Fig. 1). In order to locate the PCL, the knee specimens were examined with an arthroscopy anteriorly. A K-wire was inserted into the substance of the PCL under the arthroscopic guidance. Thereafter, the exact location of the PCL could be identified on sonograms.

To understand the spatial relation of the PCL to its surrounding structures, the adjacent soft tissues of the knee specimens were removed, leaving only the anterior cruciate ligament and the PCL. Then the angles between the PCL and the coronal planes were measured to delineate the spatial alignment of the PCL. The PCL was dissected out and immersed in a water bath for anisotropic study of the isolated PCL. The echogenicity of the isolated PCL in the water bath was assessed with the ultrasound beam at various angles to determine the anisotropy of the PCL in vitro.

We also examined 10 knee joints of five volunteers (four men and one woman, 28 to 39 years old) who had no history of trauma to the knee joints. The subjects lay prone with both knees extended. The images of the PCL were obtained by placing the transducer at the lateral margin of the medial femoral condyle and the intercondylar area of the tibia and then rotating the transducer medially (Fig. 1). Results of these examinations provided information on the normal morphology and echogenicity of the PCL in vivo. A wedged standoff pad was used to evaluate the change of echogenicity of the PCL using different angles of insonation.

**RESULTS**

The images of the knee specimens showed a well-visualized hyperechoic reflection with posterior acoustic shadow, representing the tibial cortex, with a hypoechoic band running from the femur to the tibia. One hyperechoic focus with reverberation, indicating the K-wire, was found within the hypoechoic band of the image of the knee. The image of the normal PCL was similar in all the amputated specimens and normal subjects. These findings indicate that the PCL appears sonographically as a hypoechoic band, with a hyperechoic tissue lying just superficial to it representing the posterior knee capsule and the adjacent fat (Fig. 2).

From the dissected specimen, we observed that the PCL coursed posteriorly, laterally, and distally across the joint as it passed from the femur to the tibia. It also turned on itself in an outward (lateral) spiral on its course from the femur to the tibia. The average angles between the PCL and the coronal plane on the midsagittal and axial sections of the knee were approximately 32 and 46 degrees, respectively (Fig. 3). The inclination and rotation of the PCL prevented the ultrasound beam from crossing the PCL orthogonally during the ordinary sonographic examination.

In the water bath the isolated PCL appeared as a hyperechoic band using the orthogonal sound beam.
Sonograms of the in situ PCL in the normal subjects showed a hypoechoic band. The echogenicity of the PCL increased only mildly when a proximodistal wedged standoff pad was used to make the transducer parallel to the fibers of the PCL in the sagittal plane (Fig. 5A, B). However, by tilting the transducer medially for approximately 30 degrees, the echogenicity of the PCL increased significantly (Fig. 5C, D). These findings suggest that the anisotropy of the in situ PCL comes predominantly from the mediolateral direction, which contributes to the appearance of poor echogenicity of the PCL on sonographic examination.

**DISCUSSION**

Although most severe PCL injuries are accompanied by ACL injuries as well as pathologic meniscal findings, isolated rupture of the PCL also may occur and causes significant problems, such as articular deterioration.\(^{19,20}\) Recent insights have brought a greater awareness of the importance of the PCL in preserving normal articular kinematics of the knee. Continued advances in knowledge about the PCL are required for improvements in the treatment and rehabilitation of injuries to this structure.

Despite the fact that ultrasonography has been used successfully in the evaluation of pathologic lesions of the knee joint for many years, it is still of limited value in diagnosing PCL disorders clinically.
This might be due to the lack of thorough studies of the sonographic appearance of the PCL. In this study, we inserted a K-wire into the substance of the PCL under arthroscopic guidance to verify the location of the ligament on sonograms. Using this method, we found the sonographic picture of the PCL to consist of a hypoechoic band relative to the surrounding structures on a regular sonographic examination in which the ultrasound transducer is kept neutral in the mediolateral direction.

In general, tendons and ligaments appear as moderately echogenic structures with a fibrillar pattern. The PCL consists of longitudinally organized collagen bundles with intervening loose connective tissue, which is a good ultrasound beam reflector and appears as a hyperechoic structure. However, in previous reports, most authors described the PCL as a hypoechoic structure.\textsuperscript{7,15-17} Exceptions include Suzuki and coworkers\textsuperscript{14} and Röhr.\textsuperscript{12,13} Suzuki and colleagues reported the PCL as a hyperechoic structure on both the longitudinal and transverse views.\textsuperscript{14} Röhr’s studies, both in vitro and in vivo, demonstrated the PCL as a generally hyperechoic structure with intervening hypoechoic areas.\textsuperscript{12,13} The differences in echogenicity of the PCL on sonographic examination were believed to be attributable to anisotropy of the tendon and ligament on sonographic examination.

\textbf{Figure 4} Sonographic image of the isolated PCL in the water bath (longitudinal scan). \textbf{A}, The PCL in the water bath appears as a hyperechoic band with the orthogonal ultrasound beam. \textbf{B}, The echogenicity of the PCL does not change significantly when the transducer is tilted 30 degrees in the sagittal plane to lie parallel to the PCL. \textbf{C, D}, Compared with \textbf{C}, the echogenicity of the isolated PCL in \textbf{D} is reduced markedly when the transducer is tilted approximately 30 degrees in a mediolateral direction. (The machine setting for \textbf{C} and \textbf{D} was different from that for \textbf{A} and \textbf{B}.)
Figure 5 Change in echogenicity of the PCL in normal subjects with various inclinations in angle of the ultrasound beam. A, The normal PCL appears as a hypoechoic band (arrowhead). B, The echogenicity of the PCL (arrowhead) does not change much when the transducer is tilted anteriorly 30 degrees in the sagittal plane. C, The normal PCL again appears as a hypoechoic band (arrowhead). D, The echogenicity of the PCL (arrowhead) increases markedly when the transducer is tilted medi ally over 30 degrees in a mediolateral direction so the transducer lies parallel to the PCL. T, Tibia; asterisk, posterior knee capsule and adjacent fat.
Fornage found that the specific echogenic, longitudinally oriented fibrillar pattern of normal tendons disappears on a sonographic examination if the angle of the interrogating ultrasound beam was changed. Crass and associates used the calf tendon of cattle to demonstrate the phenomenon of anisotropy. In their study, the tendon was hyperechoic relative to surrounding muscles when the ultrasound beam was orthogonal to the scanned tissue, whereas it became isoechoic at angles of 2 to 7 degrees and hypoechoic at greater angles.

Anisotropy was due to the tilt of the interface, yielding a specular reflection to the transducer, after which the reflected ultrasound beam reached the transducer with markedly decreased energy.

Anatomically, the PCL attaches on the lateral aspect of the medial femoral condyle, then passes posteriorly, laterally, and distally to attach on the posterior intercondylar area of the tibia. On its anteroposterior path, the PCL lies at an angle of about 30 degrees to the coronal plane in the mid-sagittal section. Moreover, the PCL turns on itself with an outward rotation and intersects the coronal plane on the axial section at an average angle of 46 degrees. In this study, the echogenicity of the PCL increased markedly when the transducer was tilted medially on the axial plane (horizontal plane) in vivo and in vitro. However, the echogenicity of the PCL increased only mildly when a proximodistal wedged standoff pad was used parallel to the transducer to the PCL on the sagittal plane. These facts imply that the major portion of the anisotropy of the PCL occurring during sonographic examination is from the self-rotation of the PCL.

The isolated PCL in the water bath appeared highly echogenic in this study. The PCL consists of several dense fibrous bundles with varied amounts of twisting, depending on the position of the knee. Its special anatomic architecture produces a sonographic appearance that is not exactly the same as that of other tendons and ligaments. The twisted fascicles cause more anisotropy. However, the twisting phenomenon of the fibrous bundles disappeared when the PCL was dissected out, and the fibrous fascicles became parallel. The reflected ultrasound signal increased markedly and the echogenicity of the PCL increased. This is the reason, at least partially, why the isolated PCL is more echogenic than the in situ PCL.

Most examiners agree that the PCL should be scanned from the posterior approach with full extension of the knee. Suzuki and coworkers placed the transducer on the center of the knee and then rotated the transducer about 30 degrees medially. Our method of scanning was similar to that of Suzuki and colleagues, using the hyperreflective cortex of the intercondylar notch of the femur as a landmark. We then traced the PCL upward to its origin at the medial condyle of the femur. At the tibial site of the PCL, the posterior knee capsule appeared as a hyperechoic band closely applied to the PCL and separated from the PCL at the femoral origin. Although no gross pathologic lesions could be found in the PCL of the amputated specimens by inspection, it is difficult to rule out possible intrinsic abnormalities of the PCL in this study without histologic examination. Similarly, subclinical lesions might exist in the PCL of the subjects in this study and be unrecognized without MR imaging or arthroscopic examination. These are limitations of this study. Although our investigation has demonstrated the normal sonographic image of the PCL, further studies are needed to verify the effectiveness of ultrasonography in detecting pathologic conditions of the PCL clinically.

The in situ PCL appeared as a hyperechoic band relative to the surrounding tissue on sonographic examination. When the PCL was isolated and immersed in a water bath, it appeared hyperechoic. The low echogenicity of the PCL was caused by the phenomenon of anisotropy, which mainly reflected the angle formed between the PCL and the coronal plane on the axial section. Further studies are necessitated to define the effectiveness of ultrasonography in detecting pathologic lesions of the PCL.

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