Application of High Resolution Ultrasound for Examination of the Knee Joint

Yi-Pin Chiang, Tyng-Guey Wang, * Henry L. Lew

High resolution ultrasound (HRUS) has been used in the assessment of knee pathology for a few decades. However, its role as a valid imaging tool still needs to be determined. The specific scanning methods, different types of lesion, and operator dependence might account for the variation in its reported efficacy in different studies. Some clinicians use HRUS as a first-line imaging modality to detect soft tissue injury of the knee; however, others have questioned its accuracy. HRUS can detect lesions of the suprapatellar recess, patellar tendon, medial and lateral collateral ligaments, medial and lateral menisci, and posterior cruciate ligaments. This article describes common pathologies of the knee, discusses the efficacy of sonographic examination, and outlines its clinical applications.

KEY WORDS — knee, ligament, meniscus, sports injury

Introduction

While magnetic resonance imaging (MRI) has gained general acceptance as the standard noninvasive tool in diagnosing soft tissue lesions of knee joints [1–4], high resolution ultrasound (HRUS) has also been widely used as a screening imaging tool for decades [5,6]. The advantages of HRUS include low cost, no radiation exposure, direct visualization of soft tissues, and a readily available dynamic study [5,6]. However, its efficacy is still debated in some areas, particularly in intra-articular lesions [7,8]. Previous studies have shown that HRUS can be very useful in identifying extra-articular lesions, such as pathology in the patellar tendon, prepatellar bursa, and medial and lateral collateral ligaments [9–11].

In addition to identifying knee effusion, HRUS can also reveal important information about internal derangement of the knee [12,13]. The application of ultrasound to determine intra-articular lesions such as meniscal tears has also been conducted, but its sensitivity and specificity have been shown to vary greatly. For internal ligaments of the knee, such as the cruciate ligaments, numerous articles have discussed the issue of diagnostic accuracy; however, many points require clarification. For example, the anterior cruciate ligament (ACL) may not be visualized directly on sonogram. Thus, indirect methods are needed to establish better accuracy [14,15]. In contrast, the posterior cruciate ligament (PCL) can be visualized well by sonogram but there are very few studies regarding its accuracy [16–18].

Department of Physical Medicine and Rehabilitation, Mackay Memorial Hospital, 1Department of Physical Medicine and Rehabilitation, National Taiwan University Hospital, School of Medicine, National Taiwan University, Taipei, Taiwan, 2VA Palo Alto Health Care System, Palo Alto, and 3Stanford University, School of Medicine, Stanford, California, USA.

*Address correspondence to: Dr. Tyng-Guey Wang, Department of Physical Medicine and Rehabilitation, National Taiwan University Hospital, 7 Chung San South Road, Taipei, Taiwan.

E-mail: tgw@ntu.edu.tw
In this article, lesions of the knee joints will be divided into extra-articular and intra-articular. The extra-articular lesions include pathologies of the patellar tendon, prepatellar and infrapatellar bursa, as well as the medial and lateral collateral ligaments. The intra-articular lesions consist of knee effusion, and lesions of the meniscus, as well as the ACL and PCL. Normal sonographic images of the knee joint will be described first, and then common pathologic images will be illustrated. Finally, we will briefly discuss the clinical application of HRUS.

Extra-articular Lesions

**Patellar tendon**

HRUS has been used to evaluate the patellar tendon for more than 20 years [19–23]. HRUS can easily detect changes in thickness and echotexture of the patellar tendon (Figs. 1A and 1B), which are the basic characteristics of sonographic findings in tendinopathy. In a study of 24 athletes with patellar tendinosis who underwent tenotomy, ultrasonographic findings were proven to be consistent with those of both MRI and histopathologic results [11].

In patellar tendinosis, sonography showed thickening and hypoechoic change in the patellar tendon [10]. The hypoechoic lesions were more frequently located at the upper insertion of the patella than its lower insertion to the tibia [10,22]. Thickening of the tendon is usually localized, and whole tendon thickening is only seen in severe injury [10]. Color/power Doppler ultrasonography is also a useful tool in assessing the status of the patellar tendon (Fig. 1C). Hyperemic change within the hypoechoic zone of the patellar tendon implies the presence of acute inflammation [5,9,24,25].

HRUS is also useful in the diagnosis of osteochondrosis [21], such as Osgood-Schlatter disease [21,26]. Osgood-Schlatter disease, characterized by tibial apophysitis, results from repetitive avulsion force of adolescent tibial apophysis [24]. Sonographic findings in this condition have demonstrated swelling and hypoechoic change in the distal patellar tendon combined with irregular tibial cortex at the insertion of the patellar tendon (Fig. 2). Bony fragments are occasionally found in these lesions [26].

**Prepatellar and infrapatellar bursa**

The prepatellar bursa is a thin layer of fluid that is located superficial to the patellar bone and proximal third of the patellar tendon and has a diameter of less than 2 mm [27]. Prepatellar bursitis, also known as “housemaid’s knee”, may be caused by acute or repetitive trauma of the anterior knee. Prepatellar bursitis shows distended bursa with an...
anechoic, well-margined mass and posterior enhancement (Fig. 3) [5,6]. Sometimes, the internal septum may be observed in severely distended bursa. Echogenic synovial proliferation is usually found in the bursa of those patients with rheumatoid arthritis or systemic inflammatory disease [6]. For the purpose of diagnosis and treatment, we can perform needle aspiration under sonographic guidance.

Medial and lateral collateral ligaments

The medial collateral ligament (MCL) is composed of two layers. The deep portion is composed of the meniscofemoral and meniscotibial ligaments, which are tightly attached to the medial meniscus [6]. The superficial portion is broad and flat, with fibrillar connective tissue running from the medial femoral epicondyle to its tibial attachment (Fig. 4A) [6]. The deep portion of the MCL is more prone to tearing than the superficial portion [28]. The torn MCL shows thickening and heterogeneously hypoechoic change of the ligament on sonogram (Fig. 4B).

Although HRUS has been used routinely to evaluate tears of the MCL, well-controlled blinded studies on this topic are still lacking. In a study of 16 patients with a clinical diagnosis of MCL injury, the sensitivity of ultrasound in detecting MCL tears was as high as 94% [29]. Only six of these tears were proven by MRI. In another study, the authors applied valgus force to the knee when performing ultrasound examination. The patients with MCL lesions were shown to have widening medial joint space on sonogram [30]. Using this dynamic maneuver to detect MCL tears, the sensitivity was 87%.

To our knowledge, there are no reports to describe the accuracy of HRUS in detecting lesions of the lateral collateral ligament (LCL), although clinically, HRUS has been used regularly. The LCL has been depicted as a hypoechoic thin band-like structure, because its oblique orientation causes an anisotropic effect (Fig. 5) [28]. A careful trace of the ligament from its distal insertion in the fibular head to the proximal femoral insertion provides a whole evaluation of the LCL.

Intra-articular Lesions

Effusion

Knee effusion due to traumatic or non-traumatic causes is evaluated at the suprapatellar pouch with the knee extended or slightly flexed [31]. Effusion is
compressible, and the sonographer should be cautious not to exert plethoric force through the transducer during scanning (Fig. 6). In a cadaver study, the smallest amount of installed fluid detectable by ultrasound in the knee was 7.4 mL of synovial fluid or 9.7 mL of blood [32].

The presence of knee effusion in acute injury strongly implies the existence of knee internal derangement. Kolman et al found that 80% of subjects with a suprapatellar pouch thicker than 10 mm had internal derangement, such as meniscal tear, patellar microfracture or ACL injury, in an MRI study [12], while 86% of subjects with an effusion of less than 10 mm of the prepatellar pouch had no internal derangement. This study suggested that a thickness of 10 mm of the suprapatellar pouch on
sagittal view of MRI could be the threshold value to distinguish between physiologic and pathologic joint fluid. Wang et al used HRUS to evaluate knee effusion and found that subjects with knee effusion yielded a positive predictive rate of 91.6% for internal derangement [13]. In the same study, the authors found that the sensitivity of ultrasound in detecting joint effusion was 79% and the specificity was 50% [13]. Although ultrasound is superior to clinical examination in detection and localizing knee effusion [33,34], its accuracy is still unsatisfactory [35].

### ACL

In spite of the clinical importance of visualizing the ACL, it is still not possible to directly visualize the ACL using sonography. The diagnosis of ACL tears by HRUS mentioned in several studies was based on indirect sonographic signs. Since 70% of acute ACL tears are combined with hemarthrosis [36], which probably arises from the femoral attachment of an acutely disrupted ACL [15], the accumulated fluid in the intercondylar notch of the femur on sonogram is taken as an indirect sign of ACL tear on sonographic examination. Using this method to detect ACL injury, patients are placed in the prone position with the affected knee extended; this position is more comfortable for patients with acutely swollen joints, and the transducer is then used to scan the posterior knee on transverse view.

Skovgaard Larsen et al found that this method had a positive predictive rate of 93% in detecting ACL tears [14]. However, only 11 patients in this study were confirmed with ACL tears by arthroscopy, and the remaining patients were simply diagnosed during clinical follow-up. When reviewing the previous studies using this method, the sensitivities in detecting ACL tears ranged from 88% to 96%. Since the hematoma from ACL rupture will reduce gradually [15], the accuracy of this technique will therefore decrease with time. Table 1 shows the sensitivity, specificity and positive predictive rates of detecting ACL rupture by ultrasound. While scanning hematoma to diagnose ACL rupture, intra-articular ganglion must be remembered in the differential diagnosis because of their similar sonographic presentation (Fig. 7) [7,43]. Generally, the margin of a ganglion is more well-defined than that of a hematoma.

The other indirect method to detect ACL tears is to measure the ventral translation of the tibial head [30,42]. In an MRI study, anterior translation of the tibia occurred in 67% of cases with ACL tears [3]. With dynamic ultrasound examinations, translation of the tibial head greater than 3 mm or more yielded a sensitivity of 70–95% and a specificity of 83–98% in the diagnosis of ACL rupture [30,42] (Table 1). Since the periarticular muscle is poorly relaxed in the acute stage of knee injury, measurement of tibial

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**Fig. 6. Effusion of the knee.** (A) Effusion usually presents as a distended anechoic mass at the suprapatellar pouch. (B) Disappearance of anechoic mass (effusion) due to compression of the transducer.
translation to detect ACL rupture is only suitable for chronic injury of the ACL [14].

Although direct visualization of the ACL with ultrasound is thought to be difficult [44], Suzuki et al reported successful inspection of the ligament using an anterior approach with the knee flexed more than 90 degrees and maximal internal rotation in six patients [45]. So far, this method of direct inspection of the ACL is still not generally recognized.

\[\text{PCL}\]

In contrast to the ACL, ultrasound can be used to directly visualize the PCL. The PCL is a fan-shape structure which runs posteriorly, laterally, and distally across the joint as it passes from the femur to the tibia [46]. Sonographic examination of the PCL is performed from the popliteal fossa with the knee fully extended. Because of the natural course of the ligament, ultrasound can visualize the PCL only at its distal half of the tibial insertion.

There was conflicting information about the echogenicity of the PCL [45,47,48] before the study of Wang et al [46] in 1999. Using five amputated knees, Wang et al successfully proved the echogenicity of the PCL to be echogenic extracorporeally and hypoechoic \textit{in situ}. The hypoechoic appearance of the PCL was mainly due to an anisotropic effect, and the echogenicity increased as the transducer was tilted to lie parallel to the ligament [46].

Table 1. Result of various studies concerning sonography of anterior cruciate ligament rupture (ACL)

<table>
<thead>
<tr>
<th>No. of patients</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive predictive value (%)</th>
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<tr>
<td>Indirect sign</td>
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<tr>
<td>Skovgaard Larsen and Rasmussen [14]</td>
<td>62</td>
<td>88</td>
<td>98</td>
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<td>Richter et al [37]</td>
<td>136</td>
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<td>93</td>
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<td>Ptasznik et al [15]</td>
<td>37</td>
<td>91</td>
<td>100</td>
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<td>Chylarecki et al [38]</td>
<td>193</td>
<td>91</td>
<td>78</td>
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<tr>
<td>Ritzmann and Weyand [39]</td>
<td>136</td>
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<td>93</td>
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<tr>
<td>Wittner and Muller-Farber [40]</td>
<td>117</td>
<td>96</td>
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<td>Ventral translation</td>
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<tr>
<td>Schwarz et al [41]</td>
<td>58</td>
<td>85</td>
<td>91</td>
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<tr>
<td>Chylarecki et al [42]</td>
<td>243</td>
<td>95</td>
<td>98</td>
</tr>
<tr>
<td>Friedl and Glaser [30]</td>
<td>84</td>
<td>70</td>
<td>98</td>
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<td>Direct scanning of ACL</td>
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<td>Suzuki et al [45]</td>
<td>9</td>
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Modified from reference 14.
Normal PCLs are homogeneously hypoechoic with a well-defined posterior border (Fig. 8A), while torn PCLs are heterogeneously hypoechoic with increased anterior–posterior diameter and/or indistinct or wavy posterior margins [16,18] (Fig. 8B). Table 2 presents the mean thickness of normal and injured PCLs. Bony fragments can also be detected in the case of avulsion fracture at the tibial insertion [16]. In such cases, double cortical contours can be seen on the sonogram.

It is still difficult to distinguish a partial tear from a complete tear of the PCL by ultrasound. In addition, published articles on ultrasound examination of the PCL are limited, and the accuracy of this technique is still under investigation.

Meniscus
Meniscus is the earliest intra-articular structure defined by ultrasound [30,49,50]. Normal meniscus is represented as a triangular-shaped hyperechoic structure located at the joint space (Fig. 9A). Meniscal tears usually appear as hypoechoic or anechoic clefts within the structure (Fig. 9B) [6]. Selby et al created 20 meniscal lesions in 10 knees of five cadavers and correctly detected all lesions by ultrasound [49]. However, the sonographer was not blinded to the lesions in this study. Using a linear transducer, the sensitivity of sonography in detecting meniscal lesions ranged from 82.2% to 93.3% in previous studies [30,50,51]. Najafi et al utilized micro convex probes to scan the menisci and claimed a sensitivity of 100% and specificity of 95% in detecting meniscal tears [52]. However, only the posterior horns of menisci were scanned, and only patients with positive sonographic findings were confirmed by arthroscopy. This made the clinical value of these results limited.

In contrast, Azzoni et al [8] declared that ultrasound yielded very low sensitivity (60%) and specificity (21%) in diagnosing meniscal tears in a study of 321 patients. These authors concluded that sonography was not accurate enough to be used as
the only imaging modality for diagnosing meniscal tears. However, the majority of tears in the study were vertical tears (73%), differing from a previous study with predominantly horizontal tears [53].

Since the meniscofemoral ligament may mimic vertical tears of the meniscus and cause false-positive findings, the low accuracy of ultrasound in detecting meniscal tears in this work is questioned [54,55].

Meniscal cysts, which is used synonymously with parameniscal cysts, present as cystic masses adjacent to the meniscus (Fig. 10). Ultrasound can detect meniscal cysts with a sensitivity up to 97% [56]. A high number of concomitant meniscal cysts and meniscal lesions have been noted. The association between lateral meniscal tears and lateral meniscal cysts ranged from 84% to 88% [56,57], whereas medial meniscal tears coexisted with medial meniscal cysts in about 85% [58]. A ganglion may mimic a meniscal cyst on sonogram; however, a ganglion is not usually in contact with the meniscus directly [56].

**Conclusion**

HRUS is a good imaging modality for examining various knee pathologies. It can provide an accurate diagnosis for extra-articular lesions such as patellar tendonitis, distended prepatellar and infrapatellar bursa, as well as tears of the medial and lateral collateral ligaments. With the exception of knee effusion, HRUS in the detection of intra-articular lesions, such as meniscus, as well as lesions of the ACL and PCL, requires improvement.
References


