

**“VICTOR BABES” UNIVERSITY OF MEDICINE AND PHARMACY
TIMISOARA**

FACULTY OF GENERAL MEDICINE

DEPARTMENT XV – ORTHOPEDICS-TRAUMATOLOGY II

STOIANOV ANCA GABRIELA



DOCTORAL THESIS

**INTEGRATIVE ULTRASOUND APPROACHES FOR
COMPREHENSIVE EVALUATION AND MANAGEMENT OF
LIGAMENT INJURIES AND NERVE PATHOLOGIES**

Scientific Coordinator

PROF. UNIV. DR. JENEL MARIAN PATRASCU

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STUDY 1: POINT-OF-CARE ULTRASOUND FOR THE EVALUATION AND MANAGEMENT OF POSTERIOR CRUCIATE LIGAMENT INJURIES: A SYSTEMATIC REVIEW.

CONTEXT

The posterior cruciate ligament (PCL) is one of the four major ligaments of the knee, providing approximately 95% of the total restraining force to posterior tibial displacement. Despite its critical role in maintaining knee stability, PCL injuries are less common than other knee ligament injuries, although they can cause significant functional impairment and early-onset osteoarthritis if not appropriately diagnosed and managed. Traditional methods of assessing PCL injuries include physical examination, magnetic resonance imaging (MRI), and arthroscopy, while MRI remains the gold standard diagnostic modality.

Point-of-care ultrasound (POCUS) is a rapidly evolving technology and has been increasingly used in various clinical settings for its advantages such as being a non-invasive procedure, providing real-time imaging, and improving the cost-effectiveness of patient management. In musculoskeletal medicine, the utilization of POCUS has expanded dramatically, enabling healthcare professionals to diagnose and manage a wide range of soft tissue injuries, including ligament and tendon injuries, in a more timely and efficient manner.

However, the use of POCUS in the evaluation and management of PCL injuries has not been thoroughly examined in the literature. Few studies have investigated its reliability, accuracy, and clinical applicability in diagnosing PCL injuries or providing the guidelines for treatment decisions compared to standard diagnostic tools such as MRI. Moreover, there are limited data available on the potential influence of POCUS use on patient outcomes and healthcare costs in the context of PCL injuries.

This study aims to fill the gap in the literature by systematically reviewing the available evidence on the use of POCUS for the evaluation and management of PCL injuries. The study's hypotheses are that POCUS has a comparable diagnostic accuracy to the gold standard MRI for detecting PCL injuries and that the use of POCUS in the management of PCL injuries might lead to improved patient outcomes and reduced healthcare costs. The objectives are to systematically review and analyze the current evidence on POCUS use in PCL injuries and to make recommendations for clinical practice based on the findings.

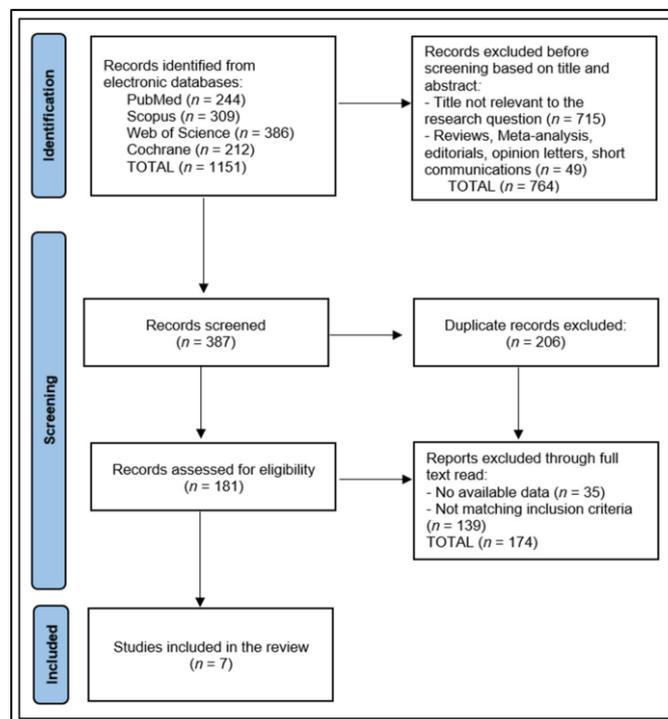
RESULTS

The systematic review included seven studies conducted across various countries such as Taiwan, Korea, India, Italy, and Japan, spanning from 1991 to 2017. These studies primarily focused on posterior cruciate ligament (PCL) injuries. In examining the characteristics of the patients who had sustained PCL injuries, a total of 242 patients were analyzed. The age distribution varied, ranging from 22 years in the Suzuki S et al. study to 42 years in the Cho CH et al. study. Reported causes of knee injuries included falls, traffic

incidents, and sports accidents. Varied sonographic patterns of PCL injuries were identified, with some studies highlighting a strong correlation between ultrasound and MRI appearance of these injuries.

The assessment of the accuracy of ultrasound in diagnosing PCL injuries revealed high sensitivity and specificity percentages across all studies. Wang CY et al. found ultrasound's effectiveness comparable to MRI. Wang LY et al. determined Point-of-care ultrasound (POCUS) as a reliable tool, especially for PCL thicknesses of 6.5 mm or more. Several other studies, including those by Cho CH et al., Lalitha P et al., Hsu CC et al., Sorrentino F et al., and Suzuki S et al., reported perfect or near-perfect accuracies in detecting PCL injuries. Many of these studies highlighted the potential of ultrasound as a cost-effective diagnostic tool, suggesting its potential to replace or reduce the reliance on more expensive diagnostic methods like MRI.

Figure 1 – PRISMA Flow Diagram.



CONCLUSIONS

POCUS presents as a reliable, cost-effective tool for the evaluation and management of PCL injuries. Across different geographic areas, patient demographics, and injury characteristics, ultrasound exhibited high sensitivity and specificity, comparable to the diagnostic performance of MRI and arthroscopy. These findings were consistent irrespective of the ultrasound transducer utilized, demonstrating the versatility of POCUS in a clinical setting. Notably, several studies identified distinct sonographic patterns in PCL injuries and reported a strong correlation between ultrasound and MRI findings. Furthermore, with the ability to identify PCL thicknesses of 6.5 mm or more, ultrasound may facilitate the monitoring of isolated chronic lesions. Overall, these findings underscore the substantial value of integrating POCUS into routine practice for the efficient evaluation and management of PCL injuries.

STUDY 2: DYNAMIC ULTRASOUND ASSESSMENT OF THE ANTERIOR TIBIAL TRANSLATION FOR ANTERIOR CRUCIATE LIGAMENT TEARS DIAGNOSTIC.

CONTEXT

An accurate diagnosis of ACL injuries is essential for an appropriate treatment and a good prognosis. The American Academy of Orthopaedic Surgeons (AAOS) strongly recommends a detailed history and physical examination, as well as magnetic resonance imaging (MRI), for identifying ACL injuries. However, the diagnostic accuracy of physical examination tests (anterior drawer test, Lachman test, pivot shift test) varies greatly in the literature. Magnetic resonance imaging is considered highly accurate in diagnostic ACL tears. However, performing MRI routinely for assessment of knee ligament injuries is not cost-effective and not always available. Although arthroscopy is considered to be the gold standard for the diagnosis of ACL injuries, clinical diagnosis should be made with relevant imaging examinations. In comparison with MRI, musculoskeletal ultrasound is more accessible, less expensive, with fewer impediments (e.g., metal implants, claustrophobia, pacemakers or other implants). Its reliability in assessing ligaments, tendons, muscles or joints has also been reported in several studies. To date, there are several studies assessing the efficiency of ultrasound to identify ACL injuries.

The aim of our study was to investigate the accuracy of dynamic ultrasound assessment of the anterior tibial translation, in diagnosing anterior cruciate ligament tears, and to assess its test–retest reliability. The accuracy of this method has been addressed in previous studies on acute ACL tears. We have evaluated the accuracy on injuries older than 4 weeks. To the best of our knowledge, the test–retest reliability of this assessment method used for the diagnosis of chronic ACL tears has not been studied.

RESULTS

A study was conducted on twenty-three patients who satisfied the inclusion criteria and consented to undergo evaluations using MRI and arthroscopy. The average age of the participants was 32 ± 8.42 years, with 69.56% (16 patients) being male. The majority of the participants had sustained injuries from amateur sporting events, with 9 injuries from soccer (39.13%), 10 from skiing (43.48%), and 2 from basketball (8.7%). Additionally, there were cases linked to professional sports, specifically one each from handball and soccer, accounting for 4.34% each.

Assessing the side-to-side variations in tibial translation (ΔD), a difference of greater than 1 mm was observed in 22 of the cases (95.65%). The average variation was 2.47 ± 1.25 mm during the first measurement and increased slightly to 2.71 ± 1.39 mm during the retest. MRI confirmed complete ACL tears in all 23 participants, whereas arthroscopy confirmed this in 22 cases. One case, which wasn't verified by ultrasound, was identified as a partial ACL tear via arthroscopy, and as such, no ACL reconstruction was pursued for this individual. Utilizing a 1 mm threshold for side-to-side tibial translation differences, the method accurately diagnosed complete ACL tears in 22 cases, boasting a sensitivity of 95.45% and an accuracy of 91.30%. Notably, there were significant variations between the first and second tests for anterior tibial translations in both the injured ($p = 0.0002$) and uninjured ($p = 0.01$) knees.

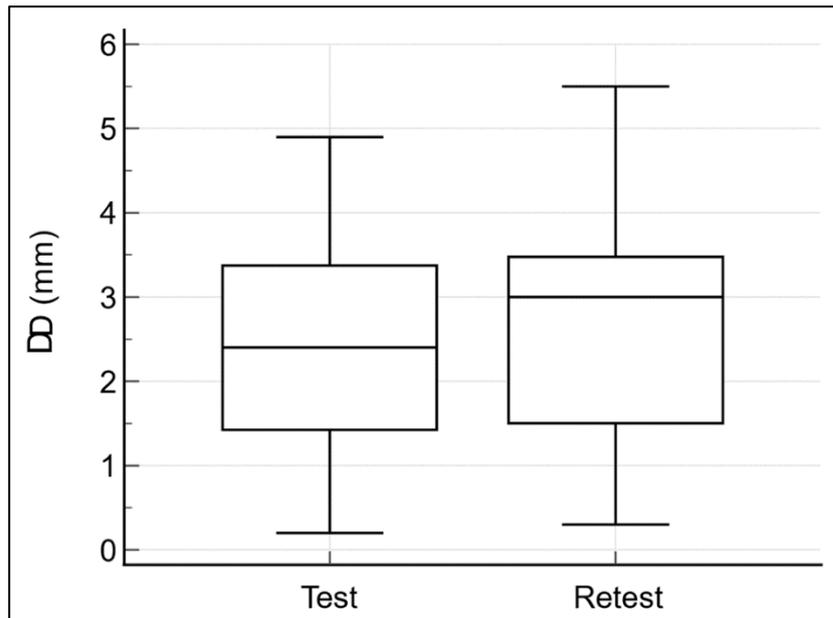


Figure 2 – Side-to-side differences in tibial translation (ΔD).

CONCLUSIONS

This research underscores the dynamic ultrasound assessment's precision and dependability in identifying anterior tibial translation, particularly in the diagnosis of unilateral anterior cruciate ligament (ACL) tears. The findings reinforce that ultrasound is not merely an imaging modality but an instrumental diagnostic tool that offers rich, insightful data about potential injuries. The inherent advantages of ultrasound, such as its non-invasiveness, affordability, and accessibility, make it an especially appealing option for clinical settings. Given the intricacies associated with diagnosing ACL injuries, which often rely on a combination of physical evaluations and imaging diagnostics, this study suggests that ultrasound should be incorporated as a complementary method alongside physical examinations. When used synergistically, these methods can enhance diagnostic accuracy, facilitating timely and appropriate medical interventions for individuals with suspected ACL damages.

STUDY 3: STATIC AND DYNAMIC ULTRASOUND EVALUATION OF THE MEDIAN NERVE MORPHOPATHOLOGY IN CARPAL TUNNEL SYNDROME DIAGNOSIS.

CONTEXT

Carpal tunnel syndrome (CTS) is a peripheral neuropathy of the median nerve, which is seen and treated by orthopaedic surgeons and plastic surgeons quite frequently as an in-office pathology.

Median nerve compression in the carpal tunnel, which is situated in between the carpal bones (having the lateral edges the pisiform and scaphoid bones) and the flexor retinaculum, can appear due to multiple causes – for instance, a narrow anatomical carpal tunnel or anatomical local changes such as cysts, osteophytes, tenosynovitis, hematomas. Median nerve neuropathy has also been seen in patients with diabetes, hypothyroidism, pregnant women and in connective tissue diseases, including rheumatoid arthritis, Sjögren's syndrome, systemic lupus erythematosus, systemic sclerosis, and vasculitis, due to the potential of these pathologies to cause various disorders of the peripheral nervous system. We highlight the importance of taking a detailed medical history and a thorough examination to assess for an underlying primary pathology.

The aim of our study was to investigate the morphopathological changes that occur in the peripheral median nerve compression syndrome in relationship with clinical evaluation and symptom onset, using ultrasound (US) imaging. In the literature, US evaluation in CTS is reported to have a sensitivity of 77.6% and a specificity of 86.8% in providing an accurate diagnosis. In our practice, early diagnosis in CTS is essential to preventing permanent muscle damage and sequelae. With the evolution of US technology which is considered to be a low-cost, accurate and fast imaging tool, along with the high-resolution transducers that have enhanced the quality of images, we can easily observe the main US changes in shape, echotexture and mobility of the median nerve in the carpal tunnel T.

RESULTS

In our study group, we noticed an 80% dominance in the female sex with CTS (of all patients, eight were females and only two males). In all ten cases, the affected hand was the dominant hand, and that was the right hand. Exactly as expected, patients had jobs in which they overused their wrist with a high number of repetitive wrist flexions and extensions such as sewers, hairdressers or software developers, where they place their dominant hand on the mouse, etc.

Clinical test results showed that thenar atrophy was present in seven patients who had symptoms of CTS for over 36 months; thenar atrophy was directly influenced by the period of time that the median nerve has suffered a direct compression. On Tinel's and reverse Phalen's tests, our results showed that Tinel's sign was positive in 10/10 patients, while reverse Phalen's test was positive in only seven of the ten examined patients. The three patients with a negative reverse Phalen's test had median nerve compression symptoms for more than 46 months; therefore, this might be related to the changes brought by the underlying neuropathy.

On the US nerve area measurement, we recorded median nerve measurements of the asymptomatic hand ranging between 8.5 mm up to 10 mm, while in the symptomatic hand the values varied between 13 mm and 19 mm. In the CTS, the standard limit for the median nerve area is a value of 10 mm; therefore, values above this threshold are considered positive test results. Ultrasound dynamic sliding of the median nerve when performing a wrist-palmar flexion was positive test in all examined patients. Side-to-side differences noted a lack of mobility of the median nerve in relation to the flexor tendons. Moreover, we noted that the lack of mobility was more obvious in cases who had CTS for more than 36 months.

In our study, we did not focus on echogenicity changes of the MN in CTS, but other studies found that, in addition to shape changes, US scanning in a standardized manner and

using a high resolution probe could identify fine echotexture changes in MN compression syndrome.

Meanwhile, back in 1997, the dynamic evaluation of the median nerve was performed and reduced transverse sliding of the nerve under the retinaculum during dynamic flexion and extension of the wrist and fingers was seen as a subjective and hard to quantify sign. Nowadays, functional ultrasonography done by an experienced sonographer using high-resolution equipment is proved to be a useful and accurate imaging tool.

While our thenar atrophy evaluation included only clinical examination and no postoperative follow up, other studies evaluated the pinch and grip strength in patients with CTS preoperatively with follow-up at three and six months after surgery. In these studies, the postoperative six-month follow-up the pinch showed an improvement of strength and grip strength by 30% and 21%, respectively. Further discussion is to be carried out on the importance of the early treatment of the CTS before the onset of thenar atrophy..



Figure 3 – Ultrasound image of the median nerve in B mode using a linear array at the carpal tunnel level; the star marking represents the median nerve longitudinal view.

CONCLUSIONS

In the current study we highlight the importance of ultrasound assessment as an in-office imaging tool accessible to orthopaedic doctors with certified training. The static and dynamic ultrasound evaluation offers the tremendous value of completing the clinical diagnosis of CTS by studying the morphology and morphopathology of the median nerve in the carpal tunnel through a bilateral standardized examination technique. There still is more to develop regarding ultrasound examination of the median nerve in CTS with regard to understanding its morphopathology and to investigating present neovascularisation with the use of Power Doppler mode and its relations to symptom onset, which can also be an interesting aspect to document in further studies due to its morphopathological importance.