

Comparison of the Effectiveness of Portable Ultrasound vs Portable X-Ray as Diagnostic Imaging of Knee Structures in Clinical Medicine

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Authors' contributions

This work was carried out in collaboration among all authors. Authors VD, DD, AT and JV designed the study, performed the statistical analysis, managed the literature searches, wrote the protocol and wrote the first draft of the manuscript under the supervision of authors SAW and SA. Authors SAW and SA read and approved the final manuscript.

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ABSTRACT

Background: Imaging techniques are providing physicians an opportunity to ensure more accurate diagnostics. While MRI and CT are the gold standard diagnostic tools, they are not utilized as primary diagnostic tools due to their size, immobility, and exposure to radiation. It is not always feasible or practical to wait for a technician in an emergency department to conduct these examinations. As technology continues to advance, diagnostic tools are becoming more portable. X-ray and ultrasound are utilized to diagnose, as well as exclude potential causes of illness. Our objective is to determine which diagnostic tool is more efficient in diagnosing patella/knee injuries.

Methods: This systematic review aims to determine which diagnostic tool is more efficient at diagnosing injuries. By collecting and reviewing existing research to compare the limitations of injury detection, the accessibility and portability of both diagnostic machines, the safety in regards to radiation exposure to patient and physician, the reliability of the diagnoses, and the costs of each machine

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Results: Of the reviewed articles, 58% of the articles focusing on knee injuries indicated that ultrasound imaging is a superior diagnostic instrument due to its efficacy and accessibility. When comparing ultrasound to x-ray directly, it was shown that ultrasound is a more precise diagnostic tool.

Conclusion: Ultrasound imaging is a more effective diagnostic tool than x-ray. It is better able to diagnose bone, soft tissue, and vessel injuries. It is a safer tool for both the patient and the physician because it uses sound rather than radiation to produce an image. It is also more accessible as advances in technology have made portable ultrasounds a protocol for quick assessments of injuries.

Keywords: Portable ultrasound; portable x-ray; benefits; disadvantages; limitations; cost; accessibility; bone; joints.

1. INTRODUCTION

The first medical imaging method was discovered in 1895 when physicist, Wilhelm Röntgen took a radiographic image of his wife's hand. In 1896, Röntgen then introduced the idea of the x-ray during the 50year anniversary meeting of the Society of Physics [1]. This clinical research was highly admired, and it took just a few weeks for Röntgen to receive his publication, which includes a radiographic photo of a finger with a glass splinter lodged in it. This began a mass production of x-ray tubes sent around the world. Diagnostic tools using x-rays, gamma rays, ultrasound, and other types of radiofrequency imaging continued to evolve, becoming more compatible with the electronic resources we currently use such as digital touch screens and computers. This allowed physicians to diagnose pathologies a lot sooner x-ray is a form of medical imaging that is used as a medical diagnostic instrument. It uses a form of electromagnetic radiation that helps the medical professional view certain structures inside the human body. The electromagnetic radiation is such a high energy source that it is able to pass through most objects and form multiple shadows that represent different anatomical structures in the body [2]. In order to create a radiographic photo, the patient is properly positioned relative to the part of the body being examined. The patient will be placed in between the x-ray lens and the x-ray detector [3]. Once the machine is turned on, radiation will enter the body and will be absorbed by different tissues. The detector will then locate these radiations, creating a photo that can be used to aid in diagnosis. The density of the image will be determined by the overall radiographic density of the structure and by the atomic number of the elements in the structure being examined. Usually, the higher the radiological density, the higher the contrast that will be produced in the image. An x-ray of the patella is the perfect example of a high contrast

image. The bone contains tremendous amounts of calcium which has a high atomic number in most tissues, making the image of a bone in an x-ray appear opaque when compared to other tissues. On the other hand, tissue structures such as muscle, fat, and other hollow structures tend to be less radiologically dense, appearing almost dark gray on image. X-ray is mostly used for diagnosing conditions like fractures, tumors or any other abnormal masses, respiratory pathologies, such as pneumonia, calcifications, foreign objects, and other injuries.

There have been a few studies that test the effectiveness of using radiographic imaging when it comes to the anatomy or overall injury of the patella. There is a belief of a high discordance when it comes to clinical and radiographic methods for patellar osteoarthritis. It was found that the features of the x-ray can be used as a diagnostic tool for patellar injuries. In some cases, it is used to estimate prognosis, a reassurance tool, and for post-therapeutic evaluation.

In some studies, it is stated that physicians use x-rays as part of a management plan in order to make decisions for patients. It is believed that this can help avoid unnecessary referrals to specialists and can be a useful aid in management plans for patients. It is also stated in another study that using radiographic imaging can help determine or predict a person's range of motion [4]. This will allow physicians to see if there is any progress or alternative ways to speed the recovery process when it comes to injuries. These are different ways physicians can assess whether the post-injury patella is healing properly rather than calcifying. Although in population studies, it is still believed that there are gaps when it comes to the relationship between x-rays and the patella.

Ultrasound began its origins with a study conducted by Donald et al., (1958) Investigating

abdominal masses by pulsed ultrasound. This study began the evolution of the ultrasound as a method of monitoring fetal well-being in obstetrics. The development of Radar by Wattson-Watt using electromagnetic waves in 1943 was later used in ultrasound and produced a 2D image. During the 1970s the advancements in circuit technology allowed for the reduction of size of machines. Machines that were once 8ft tall became portable and more accessible. In 1983, Samuel Maslak invented the Acuson 128 which had advanced beamforming software called computer tomography. These advances created new standards for spatial and contrast resolution. By this time ultrasound was capable enough to guide physicians in oocyte collection for IVF [5]. By 2000 the Doppler ultrasound was capable of 3D and 4D imaging allowing widespread usage of diagnostics in different disciplines. Ultrasound is another medical device that can be used for medical imaging. Ultrasound has a special feature that uses sound waves to produce photos inside the body [6]. These photos vary by structure, ranging from muscles to cartilage. Ultrasound is also used as a diagnostic tool that aids the physician in identifying abnormalities such as swelling and problematic infections affecting internal organs. Ultrasound is used as a guide for biopsies and to assess any damage to the heart following a heart attack. It has been proven by many studies that an ultrasound is a safe and non-invasive instrument because of its lack of ionizing radiation.

High intensity training and repeated wear-and-tear makes the knee one of the most vulnerable sites for injury. The knee bears an enormous amount of weight when performing different actions. When walking, the knee bears an equivalent of 1.5 times our body weight, when climbing stairs, the knee bears the equivalent of 3-4 times our body weight, and when squatting, the knee bears the equivalent of about 8 times our body weight. A synovial hinge joint, built of the tibiofemoral joint, which connects the tibia to the femur, and the patellofemoral joint, which connects the patella to the femur, houses a series of structures that perform functions distinct to the human body. The knee houses bursae, functional ligaments including the anterior cruciate ligament, posterior cruciate ligament, medial collateral ligament, and lateral collateral ligament, menisci, and a fibrous joint capsule that encloses synovial fluid for lubrication and a smooth range of motion. The knee also consists of differing types of cartilage that aid in

movement and stability. Fibrocartilage makes up the medial and lateral menisci and aid in stability, hyaline cartilage (articular cartilage) covers the bones that are attached by the tibiofemoral ligament and patellofemoral ligament, enabling the knee to act as a shock absorber because of the flexibility that it offers, and synovial fluid fills the joint, further enhancing the unique abilities of the knee. In addition, the quadriceps tendon, a continuation of muscle, is an elastic tissue composed of collagen that serves to allow for connection to bone and is a vital structure in providing the strength necessary to straighten the knee. Common patella injuries include: osteoarthritis, osteochondritis dissecans, infectious arthritis, chondromalacia patellae, gout, plica syndrome, rheumatoid arthritis, anterior cruciate ligament injury or tear, meniscus tear, lateral and medial collateral ligament injury, posterior cruciate ligament injury or tear, patellar dislocation and instability, patellofemoral syndrome, patellar tendon rupture, iliotibial band syndrome, pes bursitis, fracture and stress fracture, Osgood-Schlatter disease [7].

2. METHODOLOGY

This research involved a systematic literature review. The technique used in this was to gather sources that relate to the topic, analyze them and compare the results to prove or disprove the topic. In doing this, we were able to decipher whether ultrasound imaging is more useful in diagnosis and prevention of knee injuries in comparison to standard x-ray imaging. Each article was researched and reviewed to find statistics and facts that were then used to ultimately reach a conclusion and prove or disprove the hypothesis that ultrasound imaging is superior to x-ray imaging.

2.1 Inclusion/Exclusion Criteria

Included sources in this literature review must have information that applies directly to the subject matter. The source must include information regarding the quality of ultrasound or the benefits of this instrument in diagnosing knee injuries. Sources were also included if the benefits or disadvantages of x-ray and ultrasound imaging in diagnosing knee injuries was discussed. Excluded sources did not have sufficient evidence to add to the topic. Excluded sources did not have full text available. Excluded sources showed bias or flaws. If a source did not meet the intended criteria or did not pertain to the topic being discussed it was excluded.

Table 1. PICO Analysis

P	Modern day medicine is constantly seeking ways to improve. We feel there is a problem in current diagnostic testing of injuries.	The lack of progression in the diagnostic area of medicine regarding injuries can also be similar to the problems arising from more costly methods of treatment due to the resistance of change in the medical community.
I	Individuals with exposure in high-hazard occupations or individuals who participate in athletics.	The main exposure that we are considering is exposure in high-hazard occupations, including athletic occupations.
C	The use of portable ultrasound vs portable X-ray	Collecting data or statistics to compare which method is more efficient is diagnosis while being cost friendly.
O	The outcome we would like to see is that ultrasound can be used to detect injuries in a more timely and cost effective way.	We hope to improve the everyday struggles of the medical profession through the benefits of using ultrasound imaging instead of X-ray. We hope to find reasons to switch to the use of ultrasound as an alternative measure.
	What type of question are you asking?	The type of question that we are aiming to explore is one for diagnosis and therapy.
	Type of study you want to find	The best study designs and methodology for this systematic review is a controlled study (diagnosis) and a randomized controlled study (therapy).



PRISMA 2009 Flow Diagram

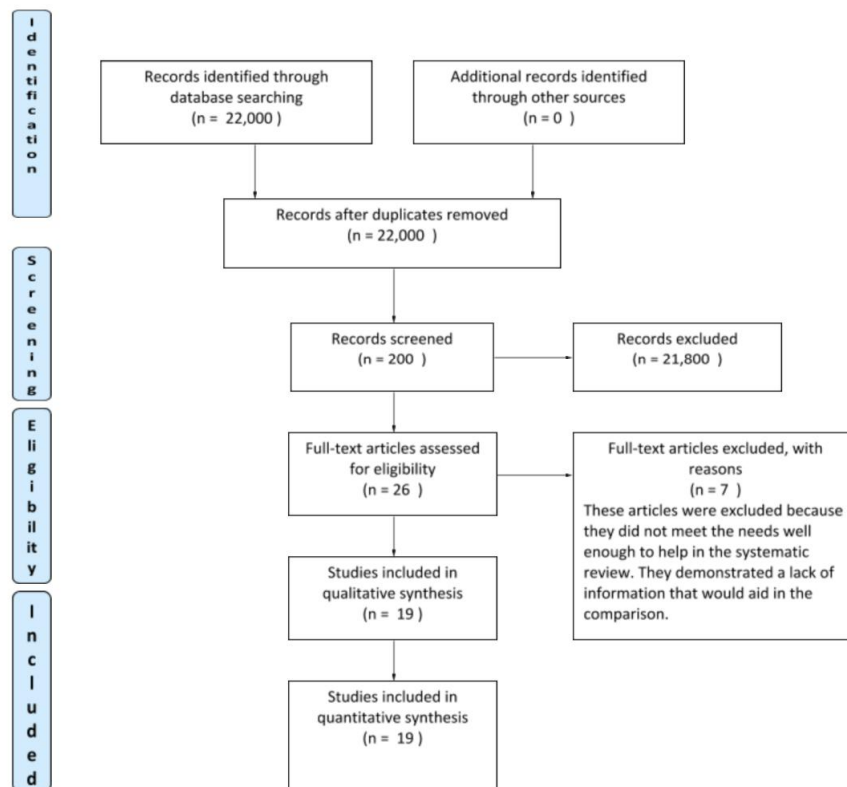


Fig. 1. PRISMA Diagram

3. RESULTS

In total, 19 articles were reviewed. Of these, 9 articles focused on the use of ultrasound, 7 on the use of x-ray, and 3 on the comparison between both diagnostic tools. This showed that 47% of the articles reviewed were about ultrasound and 37% were about x-ray. The remaining 16% of the articles were able to give a comparison between the use of ultrasound imaging and x-ray imaging.

Out of the 9 articles that focused on the use of ultrasound, 78% of them stated that ultrasound imaging is a superior diagnostic instrument due to its efficacy and accessibility, while the other 2 articles reasoned that ultrasound cannot be considered a superior diagnostic instrument because of improvements still needed.

On the other hand, 5 out of the 7, which is 71% of the articles that focused on the use of x-ray, stated that x-ray was a superior diagnostic

instrument. The other 2 articles did not agree that x-ray should be considered a superior diagnostic tool.

The last 16% out of the 19 articles gave a comparison between the use of ultrasound vs the use of x-ray. These articles stated which of the following diagnostic tools was more superior when it comes to primary diagnostics. 2 articles stated that ultrasound is more efficient due to its ability to view bones and other soft tissues. This gives ultrasound a 66.7% advantage over the use of x-ray. The other 33.3% of the 3 comparing articles did not display enough comparative evidence that ultrasound is a better choice as a diagnostic instrument. This lack of information led to the conclusion that x-ray is more efficient as a diagnostic method.

Overall, 74% or 14 of the 19 total articles reviewed focused on the knee as the structure being examined, which is the main area of interest.

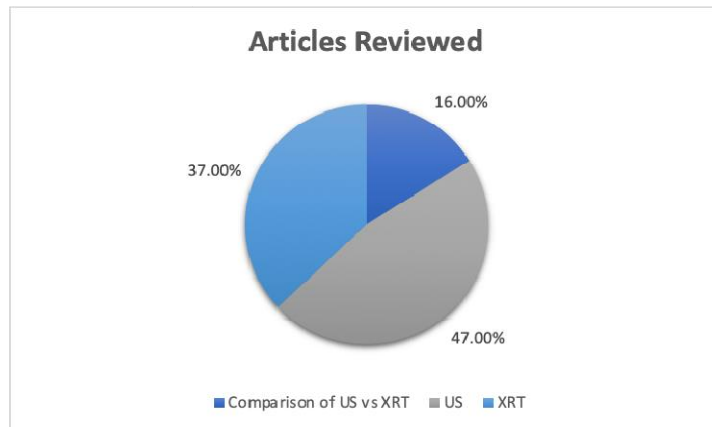


Fig. 2. Distribution of reviewed articles

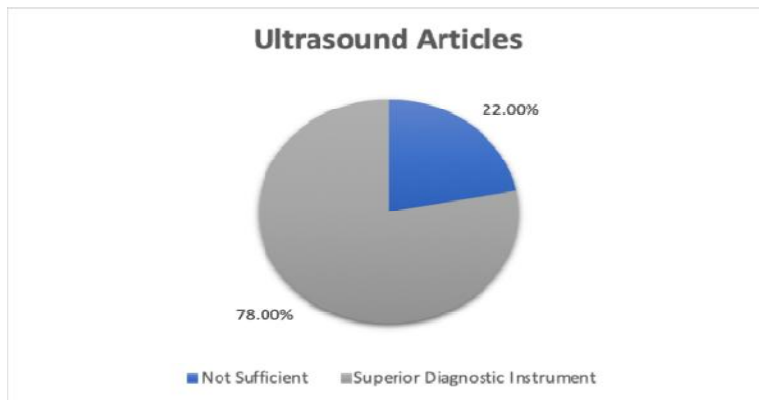


Fig. 3. Distribution of articles which show USG as superior diagnostic tool

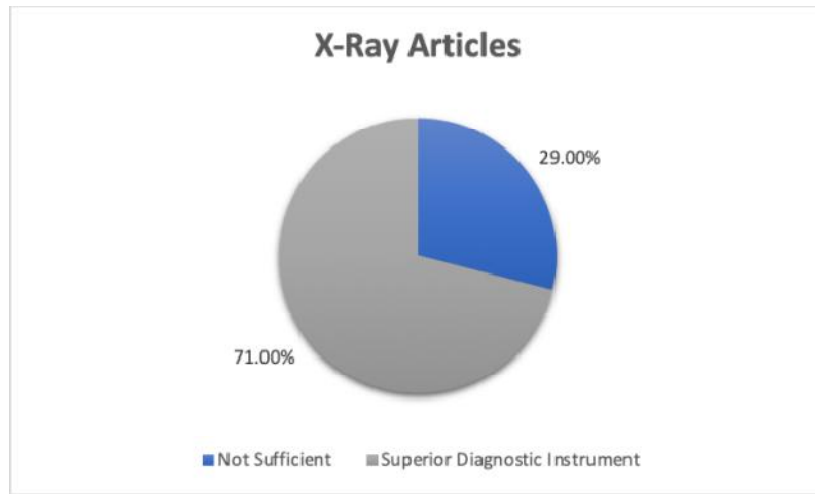


Fig. 4. Distribution of articles which show X-Ray as superior diagnostic tool

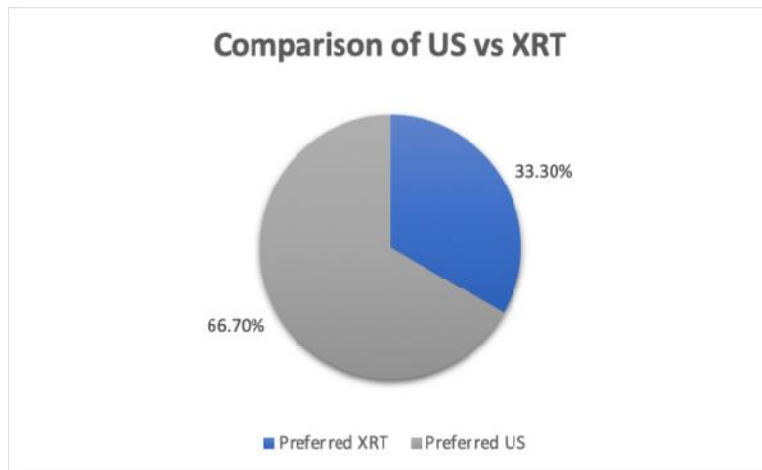


Fig. 5. Distribution of articles which compare USG and X-Ray



Fig. 6. Distribution of Knee specific articles

4. DISCUSSION

There are numerous controversial pieces of literature that attempt to prove or disprove the relationship between x-ray and ultrasound as diagnostic methods in clinical medicine. The articles reviewed attempt to explain the positive relationship between the use of x-ray or ultrasound when diagnosing pathologies of the knee.

The article written by Bedson J et al. in 2008 attempts to prove that the use of x-ray to examine and diagnose knee pain in patients, inclusive of those with a prior diagnosis of osteoarthritis, is not a sufficient instrument to be used alone. The data revealed that when examined with x-ray, the sensitivity of patients with knee pain who were identified to have osteoarthritis was 24-38%, but when examined including the patella-femoral joint the sensitivity increased to 51-67%. Although the examination increased the sensitivity, discrepancy still exists between the overall efficacy of x-ray. This is demonstrated when reviewing data that revealed a 76% sensitivity threshold max when all compartments of the patella were examined [2]. This article has proven that using x-ray imaging as a diagnostic instrument is not sufficient as the sole method of diagnosis. It is proven that although the sensitivity increased when examining different components of the knee using x-ray imaging, it still does not prove that x-ray imaging can be used as a sole diagnostic instrument. This article cannot be used to prove or disprove the hypothesis that ultrasound imaging is superior to x-ray imaging, although does demonstrate that there are more efficient methods of diagnosis available when compared to x-ray imaging.

The study conducted by Bahl A et al in 2018 attempts to compare ultrasound imaging to plain radiography (x-ray) in the examination and diagnosis of certain fractures. The randomized prospective study utilized 40 emergency medicine residents from a single site, with fractures examined on 5 chicken legs. Resident participants were given 2 minutes to examine the fracture using ultrasound and x-ray imaging, and then record the data for each chicken leg according to presence or absence of fracture, location, and type of fracture. Review demonstrated a mean of 185 ultrasound imaging scans viewed prior to beginning the study. Results of the study demonstrated a higher mean of fracture identification when using ultrasound, with a mean of 0.89 compared to x-ray with a

mean of 0.75; both having a standard deviation of 0.11. It was concluded that there was no significance in ultrasound compared to x-ray when identifying location and type of fracture. This study concluded that ultrasound imaging is a more efficient instrument for identifying such diaphyseal fractures [8]. This study has proven that ultrasound imaging is superior as a diagnostic instrument based on the demonstration that ultrasound imaging has the ability to identify components of the knee at a higher level when compared to x-ray imaging.

The article written by Bureau N et al in 2016, attempts to explain the cost effectiveness using ultrasound imaging. This article explains that current evidence recommends musculoskeletal ultrasound imaging as the primary diagnostic instrument due to its high level of accuracy and cost effectiveness [9]. Thus, the article proves that ultrasound imaging is superior as a diagnostic instrument.

The cross sectional study conducted by Pereira C et al in 2019 attempts to explain how ultrasound tissue characterization (UTC) imaging can be used for the description of patellar and Achilles tendons. Ultrasound tissue characterization imaging uses signal modelling and analysis to characterize and differentiate healthy and diseased tissue. This study aims to assess the intra and inter-rater reliability of UTC imaging in harvested and unharvested patellar tendons in patients undergoing anterior cruciate ligament reconstruction (ACLR). This study used ten harvested and twenty unharvested patellar tendons from participants that were scanned twice by the same examiner, and eleven harvested and ten unharvested patellar tendons that were scanned twice by two different examiners. It was yielded that the patellar apex, proximal tendon, mid tendon, distal tendon, and overall tendon of both harvested and unharvested patellar tendons displayed characteristics of intra-rater reliability [10]. This cross sectional study demonstrates that there is a better use for ultrasound imaging in diagnosis of component quality of the knee, specifically the patellar tendon.

The observational study conducted by Pardo E et al. in 2018 attempts to explain the outcome of using ultrasound imaging to assess components of the knee, specifically the quadriceps femoris muscle thickness in patients suffering from muscle wasting. The reliability of this instrument was tested using intra and inter-reliability

measures when assessing patients and was determined to be sufficient when assessing thickness of the quadriceps femoris muscle [11]. It was determined that ultrasound imaging may be the better instrument for diagnosis. Although it was not proven that ultrasound is a superior diagnostic instrument, it was highly indicated.

The article published by Elias A et al, in 1987 attempts to compare the use of ultrasound imaging to x-ray imaging specifically in the diagnosis of deep vein thrombosis of the lower extremities. This article performed a double blind study that assessed the limbs of 430 participants suspected of having deep vein thrombosis or pulmonary embolism. The results of this study revealed that of the legs examined there was a 98% sensitivity and 95% specificity when using ultrasound imaging. The study also yielded a 91% positive detection of isolated thrombosis of the calf [12]. Although this double blind study yielded results for detection of a different pathology, the study yielded results that correlate with the desired result of this systematic review, which is to prove that ultrasound imaging is an effective diagnostic tool.

The prospective study conducted by Cook JL et al, in 2000 attempts to predict future symptoms in a high risk population including a group of 52 elite junior basketball players. This prospective study evaluated patellar tendons at baseline and again 16 months after the initial evaluation. The study consisted of 10 case tendons and 42 control tendons. All tendons were determined to be asymptomatic at baseline, and the relative risk for development of jumper's knee was 4.2 times greater in the case tendons when compared to the control tendons. It was also found that men are more likely to display ultrasonographic changes when compared to women. The data collected suggests that the presence of ultrasonographic areas is associated with a greater risk of developing jumper's knee symptoms, and the analysis revealed that it is not possible to definitively predict tendons that would develop symptoms [13]. This study demonstrated that ultrasonography is valuable as an aid in diagnosing symptoms of knee injuries, although it cannot definitively predict a knee injury.

The case published by Halupa AJ et al, in 2019 attempts to explain the use of ultrasound imaging in the diagnosis of pseudogout. Point-of-care ultrasound (POCUS) was used to assess a patient who presented with worsening right knee pain for 3-4 weeks prior to an emergency room visit. Assessment with ultrasound revealed a

pseudo-double contour sign of the right knee as well as the presence of calcium pyrophosphate crystals seen with ultrasound-guided arthrocentesis. Assessment of the knee for calcium pyrophosphate crystals and chondrocalcinosis revealed a sensitivity of 86.7% and a specificity of 96.4%, which proves that point-of-care ultrasound (POCUS) is a valuable, effective instrument that can be used in diagnostic procedures, specifically crystalline-induced arthropathy in this case [14]. This case mainly demonstrates the ability to produce a high level of sensitivity and specificity, which aids in strengthening the hypothesis that ultrasound imaging is a superior diagnostic instrument. Although the case did not state this, the content and subsequent results led to this conclusion.

The article published by Kandel M et al, in 2019 attempts to validate an ultrasound protocol for the assessment of the anterolateral ligament of the knee. This study used a specialized technique to aid in the development of an ultrasound protocol for assessment of the anterolateral ligament. The process included short and long axis imaging of the anterolateral ligament in 36 knees from 18 healthy volunteers. Measurements of thickness, width, and distance between the anterolateral ligament insertion and lateral tibia plateau were taken and an intraclass correlation coefficient (ICC) was calculated for these measurements. Results yielded a poor inter-rater reliability for anterolateral ligament thickness, with an ICC of 0.35. Results yielded a satisfactory inter-rater reliability for anterolateral ligament length and width, with an ICC of 0.80 and 0.88 respectively. Results yielded an excellent inter-rater reliability for the distance between insertion and lateral tibia plateau, with an ICC of 0.96 [15]. Based on these results it is concluded that ultrasound imaging is a reliable and effective diagnostic instrument. This article proves that ultrasound imaging is a superior diagnostic instrument based on the results, which specifically focused on the reliability of this method. Although it does not compare ultrasound imaging to an alternative type of imaging, this article provides statistical evidence in favor of the superiority of ultrasound imaging in diagnosis.

The study conducted by Gray HA et al, in 2019 attempts to prove that generic x-ray imaging can be a reliable instrument for the identification of three dimensional motion of the knee. The study used portable x-ray imaging to assess motion during normal walking speeds in humans. The study was conducted with a population of 15

healthy individuals (9 males and 6 females), and assessed movements and rotations including flexion-extension, internal-external rotation, and abduction-adduction. The data collected from this study yielded valuable information for the assessment of knee function in normal and pathologic gait [16]. The findings in this study support the hypothesis that portable x-ray imaging is useful as a diagnostic instrument of certain components of the knee. Although due to the lack of comparison in this study, it does not support the hypothesis that an alternative method such as ultrasound imaging is a superior diagnostic method in contrast to x-ray imaging.

The article published by Shearer T et al, in 2014 attempts to explain the use of phosphotungstic acid (PTA) and iodine solution (IKI) as an enhancement tool for contrast x-ray imaging of porcine anterior cruciate ligaments and patellar tendons. This article explains that PTA was beneficial only at enhancing contrast, while IKI penetrated samples quickly and enhanced contrast after some time. Contrast levels were compared when using different types of x-ray imaging sources, and it was determined that varying components of the knee were able to be identified but there was not one single source that made all components of the knee identifiable [17]. This article aids in the hypothesis that x-ray imaging is a beneficial diagnostic instrument, but it is clear that there are flaws in this method and there are superior methods of diagnosis in contrast to x-ray imaging.

The article published by Czyrny Z et al, in 2017 attempts to explain the importance of ultrasound imaging as a diagnostic instrument, while also detailing the unsatisfactory components of ultrasound imaging in an attempt to eventually improve those components and harmonize ultrasound imaging criteria as a whole. Although ultrasound imaging is a superior diagnostic instrument, there is a need for improvement in order to raise the level of accuracy and specificity when assessing components of the body, specifically the knee [18]. This article explains the need for criteria improvement in order to further the science of ultrasound imaging as a whole unit and to further the accuracy and specificity of assessments. This article states that ultrasound imaging is superior as a diagnostic instrument, although does not go on to prove or disprove the efficacy of ultrasound imaging as a superior diagnostic instrument. Rather, it explains the criteria needed in order to further benefit this science, which would ultimately

provide strong evidence in favor of ultrasound imaging as a superior diagnostic instrument.

The retrospective study conducted by Zampogna B et al, in 2015 attempts to compare the effectiveness of standard x-ray imaging with high tibial osteotomy (HTO), an orthopedic surgical procedure designed for younger patients in an attempt to correct varus deformation with compartmental osteoarthritis. This study explains the correlations between different components of the knee using certain angles of measurement, including the hip-knee-ankle angle (HKA) and the angle between the femur and tibial axis (TFa). Using the mean values of a paired t-student test, it was proven that there is a statistically significant difference between pre-operative and post-operative measurements. The pre-operative measuring R value is 0.26, which is a poor representation while the post-operative measuring R value is 0.53, which is a fair representation. There was proven to be a weak correlation between the HKA value and TFa value, which makes this unsuitable for use in everyday practice [19]. This retrospective study proved that standard x-ray imaging and HTO could not provide sufficient evidence as a respective diagnostic instrument. This study ultimately proves that standard x-ray imaging is an inferior diagnostic instrument and further aids in the hypothesis that ultrasound imaging is a superior diagnostic instrument.

5. CONCLUSION

The sources reviewed prove that ultrasound imaging is a superior diagnostic instrument, specifically for assessing and diagnosing structures of the knee. Although there is evidence that other types of imaging, such as x-ray imaging can be used to aid in assessing and detecting abnormalities of the knee, it is highly proven that ultrasound is the superior method in differing aspects of assessment and diagnosis. Ultrasound imaging is a more efficient and cost effective diagnostic instrument in comparison to other diagnostic instruments such as x-ray imaging.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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