CURRENT CONCEPTS REVIEW

Ultrasound Applications in Pediatric Orthopedics

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Abstract

Imaging techniques have significantly impacted physicians' capability for diagnosis and differential diagnosis for decades. The aim of this review is to update our knowledge regarding the use of US in orthopedic pediatric patients for diagnostic purposes or procedural/therapeutic purposes. This review demonstrates the application of US in trauma (long bone fractures, radial neck fractures, etc.), developmental anomalies such as developmental dysplasia of the hip and congenital dislocation of the patella, soft tissue pathologies (ganglion cyst, popliteal cyst, hemangioma, lipoma, etc.), tumors, apophysitis, joint effusion, and femoral acetabular impingement. US aid in musculoskeletal procedures has also been reported; US-guided procedures such as aspiration, injection, biopsy, foreign body removal, and peripheral nerve block reduce complications, thus making the procedures safer for the patient. Sonography is a fast, low-cost, mobile, non-invasive, and radiation-free diagnostic tool. Even though US requires a skilled operator and has a long learning curve, in experienced hands is the "orthopedic surgeon's stethoscope".

Level of evidence: IV

Keywords: Child, Pediatric orthopedics, Sonography, Ultrasound

Introduction

Imaging techniques, such as ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), and X-rays have significantly impacted physicians' capability of diagnosis and differential diagnosis for decades. Currently, US has become increasingly mobile and has many specialties, apart from radiologists, for both diagnostic and therapeutic purposes. Physicians perform US at the patient's bedside without difficulty using high-resolution real-time assessment. Therefore, a new term has occurred, point-of-care US (POCUS). Emergency department (ED) doctors, skilled in the use of POCUS, can optimize patient management, improve diagnostic accuracy, and increase procedural safety. Among others, specialists that use US for diagnostic purposes are rheumatologists and orthopedic surgeons.[1]

Despite the latest advancements in other imaging techniques, US remains one of the most widely used diagnostic tools, especially for musculoskeletal (MSK) diagnosis and procedure. Additionally, dynamic US can reveal several pathological conditions during patient's movement. Moreover, US is an excellent tool for performing bedside interventions in children, like hip aspiration where the child's hip has to be placed in a specific position in order to encourage small effusions to pool in the anterior recess next to the femoral neck. Joint injections in children could be performed with the aid of US, especially for superficial joints. Foreign bodies could be localized and removed with US guidance, avoiding using ionizing radiation in children. US is a useful tool for soft tissue biopsies too with the limitation of deep lesions which are difficult to visualize.[2]

US is a first-line tool in pediatric MSK imaging, as it can be well tolerated by children without using ionizing radiation and sedation. A huge advantage of US is the visualization of non-ossified cartilaginous structures, which is extremely helpful in pediatric patients. Its cost-effectiveness in a variety of applications is of paramount importance and has led to its widespread use and adoption.[3]

The aim of this review is to update our knowledge regarding the use of US in orthopedic pediatric patients for diagnostic purposes or procedural/therapeutic purposes. This will be achieved by first addressing the

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normal sonographic appearance of different MSK structures during examination; second, by describing the application of US in different orthopedic pathological conditions; and third, by highlighting its limitations.

US technique and normal sonographic appearance

US is a widely available, inexpensive, radiation-free, comparative, and dynamic technique that has no adverse effects. It produces sonic waves (approximately 3-18 MHz) that are transferred through various body structures. Depending on the potential reflection or refraction of these waves, the emission will be absorbed by a transducer, which alters the acoustic to electric energy, resulting in the demonstration of various tissues on the operator's screen. Thus, each structure is visualized with a different echogenicity, according to its density: hyperechoic (tendons, ligaments, periosteum), hypoechoic (muscles), hyper/hypoechoic (peripheral nerves), and anechoic (liquids). Additionally, Doppler ultrasonography, which employs the Doppler effect, is valuable as it helps doctors assess the blood flow through major arteries and veins, such as those of the upper and lower limbs [Table 1]. The Doppler effect is defined as the change in the frequency of sound waves due to a reflector moving toward or away from an object.[4]

Table 1. Echogenity of structures

Skin	Hyperechoic
Sub-cutaneous	Hypoechoic (connective tissue appears hyperechoic)
Muscle	Hypoechoic with hyperechoic lines in longitudinal view and dots in transverse view
Tendon	Hyperechoic (parallel lines in longitudinal view)
Ligament	Hyperechoic
Nerve	Hyperechoic with hypoechoic lines in longitudinal view and dots in transverse view
Bone	Hyperechoic with anechoic window
Liquid	Anechoic or sometimes mixed echogenicity

Main body

Application of U/S in pediatric orthopedics

1. Trauma [Diagram 1]

Long Bone Fractures

Long bone fractures involving pediatric patients represent a significant proportion of pediatric ED visits. Although radiography is the gold standard, US has proven to be valuable for immediate and precise assessment of metaphyseal and diaphyseal fractures of long bones, including the humerus, ulna, radius, femur, tibia, fibula, metacarpals, and metatarsals [Figure 1a, 1b]. Thus, US utilization appears to be a useful time-saving alternative in the hands of emergency department physicians, making the evaluation of a suspected fracture much less painful for patients than radiography.[1] Furthermore, its ability to detect subsequent pathologies in soft tissue structures, such as hematomas and swelling, in addition to common findings, such as cortical disruption and periosteal lesions, offers a more comprehensive view of the fracture area. In addition, US has the ability to demonstrate a dynamic approach to trauma. According to Barata et al., sonography's sensitivity is higher in diaphyseal than metaphyseal fractures, since abnormal borders at the edge of the bone and growth plates' existence might limit its accuracy.[5] However, a recent meta-analysis conducted by Douma-den Hamer et al. showed that US has high accuracy not only in diagnosing distal forearm fractures but also in reducing them under US guidance. According to the same meta-analysis sensitivity was 97% and specificity was 95% for detecting distal forearm fractures.[6]

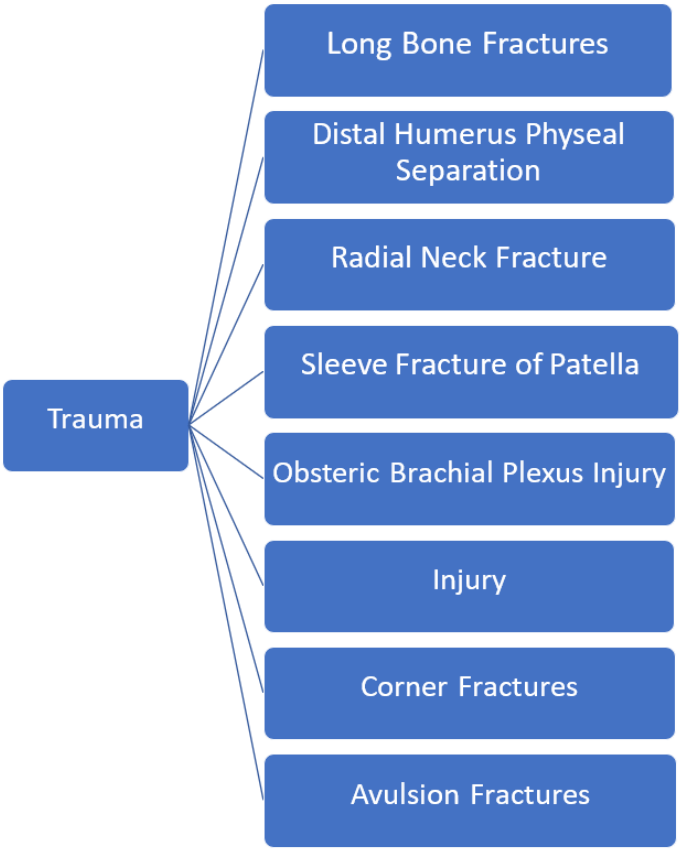

Diagram 1. Long Bone Fractures

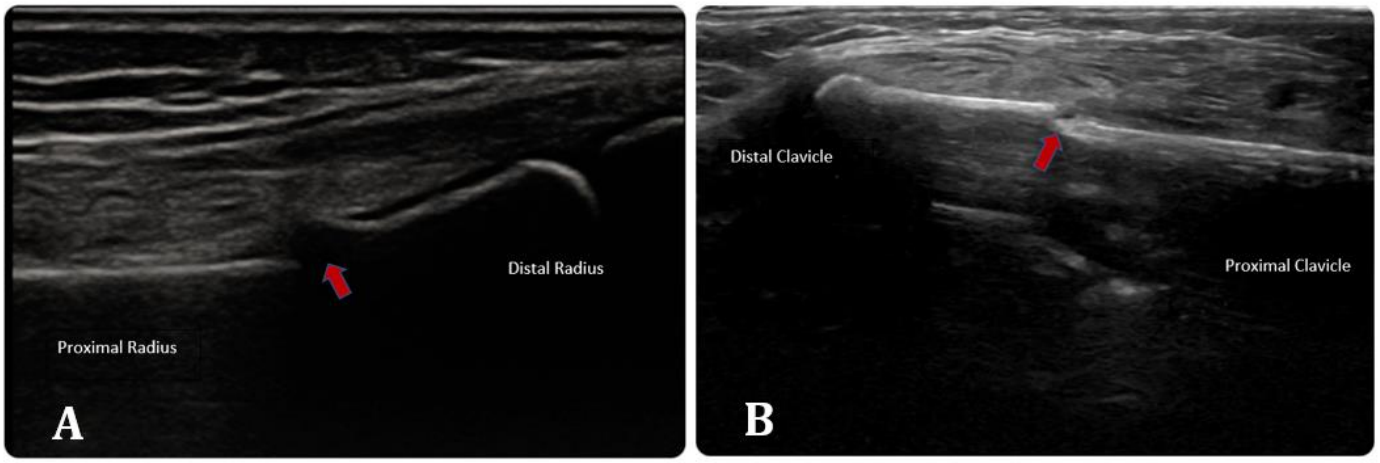

Figure 1. Fracture (red arrow) of distal radius [figure 1a] in a 10y boy. Mid-shaft clavicle fracture (red arrow) in a 12y old girl [figure 1b]

Distal Humerus Physeal Separation

Distal humerus physeal separation is an uncommon elbow fracture seen in children under three years of age and is frequently associated with labor; nevertheless, child abuse should also be considered as a cause. US should be adopted as an additional imaging technique when plain radiography is unable to set the diagnosis due to the underdeveloped cartilage structure of the area at that age. During static US examination, detection of separation of epiphysis from the metaphysis is being highlighted by noting the lack of cartilage at the distal humeral metaphysis. On the other hand, dynamic examination revealed instability of the epiphysis relative to the metaphysis. Therefore, sonography could contribute to the diagnosis of this usually missed fracture.[7,8]

Radial Neck Fractures

Radial neck fractures are relatively common traumatic injuries that usually affect juveniles. Its pathophysiology is associated with extension and valgus loading injuries of the elbow.[9] In younger children, where the radial head is mostly cartilaginous, US appears to be an effective technique for diagnosis because it could provide detailed pictures of soft tissue in contrast with typical x-rays. Furthermore, according to Su et al., ultrasound-guided reduction seems to be a safe and reliable option for treating displaced radial neck fractures with close reduction. In addition, US on the hands of an experienced surgeon can help avoid posterior interosseous nerve injury by continuously monitoring its position around the elbow.[10]

Sleeve Fracture of Patella

Sleeve fracture of the patella is a rare injury in the pediatric population, characterized by the separation of the cartilaginous part from the ossified patella. Indirect injury caused by powerful contraction of the quadriceps muscle applied to a flexed knee is the most common mechanism of injury. This fracture pattern most commonly occurs in the inferior pole of the patella, and due to its cartilaginous structure, clinical and radiographic diagnosis can be challenging. If that is the case, US is highly recommended to further evaluate the nature of the injury. Disruption of the cartilage may be seen, combined with soft tissue edema, fluid, and hyperemia.[11]

Obstetric Brachial Plexus Injury

Brachial plexus injury during birth refers to injury to the perinatal period caused by the application of external force to the neck of the newborn during childbirth and may result in flaccid paralysis of the upper limb. It is frequently localized in–C5-C6 roots. For brachial plexus birth injury to be diagnosed, preganglionic and postganglionic findings should be assessed with the aid of imaging modalities. According to Gunes et al., MRI is used as the primary imaging technique; however, US can be of great importance when it comes to postganglionic injury, especially between C4-C7 roots. This study showed that US had 84% sensitivity and 100% specificity for detecting post-ganglionic injury when compared to MRI. Even though, every post ganglionic injury at the level C4-C7 were detected, US could not detect T1 injuries and occasionally C8 injuries because of an narrow window for examination. Thus, US appears to be a valuable assisting technique in postganglionic upper and medial trunk cases both during the initial clinical examination and the follow-up period because of its fast application and its real-time nerve assessment without sedation.[12]

Corner Fractures

Corner fractures, also known as classical metaphyseal lesions (CML), are usually found in children younger than 2 years of age. In infants without underlying bone disease, this type of fracture is highly specific for non-accidental injury (NAI), which often occurs with repetitive acceleration and deceleration forces as an infant is shaken, but may also reflect torsional forces as an infant's limb is twisted.[13] These lesions are mostly seen in long bones, such as the femur, tibia, and humerus. Certain studies have attempted to assess the

diagnostic utility of US using radiographic signs as reference points. US reliability was based on abnormalities observed in the metaphyseal bone collar and the echogenic area between the metaphysis and cartilaginous epiphysis. Due to its low sensitivity but high specificity, a negative US cannot exclude CML. Thus, when plain X-rays are equivocal, positive US can help validate the diagnosis.[13,14]

Avulsion Fractures

Avulsion fractures are rare lesions that are usually detected in young athletes. The mechanism of injury usually involves excessive force applied to the bone due to sudden and forceful contraction of the tendon or ligament. As a result, a small piece of bone will avulse from the main bone and remain attached to the tendon or ligament. This type of fracture can be caused by any activity that involves kicking, jumping, or having to speed up or slow down very quickly and are mostly seen in the pelvis, knee, and foot.[15] Although plain radiography is the gold standard, US can be a valuable tool in assessing apophyseal injuries that will reveal a hypoechoic zone in the region of the apophysis extending to the surrounding soft tissue; sometimes, it can be combined with Doppler sonography, showing hyperemia in the affected area.[16]

2. Developmental anomalies

Developmental Dysplasia of the Hip

Developmental dysplasia of the hip (DDH) appears as an abnormal development of the anatomical elements of the femoral head and acetabulum, classified from mild dysplasia to total hip dislocation. US is the gold standard in the early diagnosis and treatment of DDH, reducing the rate of late DDH and the need for surgical procedures simultaneously. It is crucial to mention that the second ossification center appears around the age of 6 months; thus, for newborns with suspicious clinical signs until this period, US is the favored assessment tool. Caution must be taken for newborns until 4 weeks of age, because an immature hip could be misdiagnosed as DDH and entrain overtreatment. During sonographic screening, certain femoral head planes (base, bone, and cartilage roof plane) must be viewed so that DDH can be diagnosed, classified, and treated accordingly [Figure 2a, 2b]. The position of the femoral head is assessed by three lines and two angles: base line, bony line and cartilage roof line, α angle (between base and bony line) and β angle (between base and cartilage roof line). Based on these measurements hip dysplasia is categorized into four types according to a widely accepted Graf classification, in which type I does not require any treatment and type IV is the most severe case with the worst prognosis.[17]

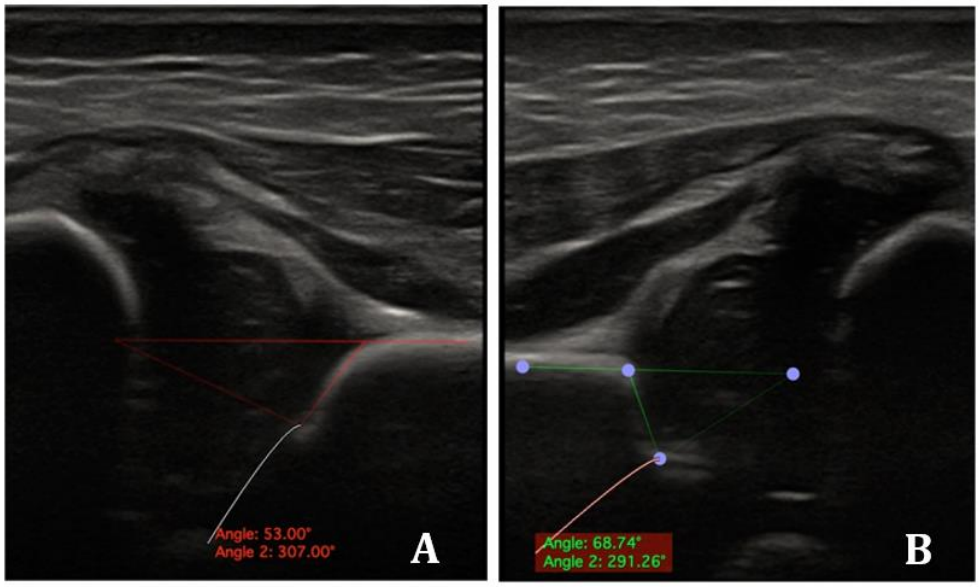

Figure 2. Developmental Dysplasia of the Hip. Pathologic hip with abnormal α angle 53o (Graf type IIa (-)) in a 7 weeks old girl [figure 2a] Normal hip with α angle > 60o (Graf Type I) in a 5 weeks old boy [figure 2b]

Congenital Dislocation of the Patella

Congenital dislocation of the patella is a permanent and undiminished condition usually observed during childbirth with genu valgum, tibial rotation, and flexion contracture. Early diagnosis is important to avoid complications and facilitate recovery.[18,19] While X-ray is the gold standard for assessing patellar dislocation in older children and adults, US in newborns and infants may be of great importance in order to quickly and easily evaluate the non-ossified cartilaginous patella. Furthermore, US can provide valuable information to the surgeon through its complete and detailed view of the knee joint, especially when combined with dynamic examination.[19]

3. Soft tissue [Diagram 2]

Ganglion cyst

Ganglia mostly appear in the wrist, but the literature indicates that ganglion cysts may emerge in many different locations. US is the initial method for the diagnosis of ganglion cysts in both children and adults due to its non-invasive nature and high prognostic rate. US reveals an anechoic to hypoechoic mass with well-defined margins, folded by a thin wall, allowing for assessment of the cyst's size and preoperative planning [Figure 3a].[20]

Popliteal cyst

Popliteal cysts, also known as Baker's cysts, rarely appear in the juvenile population. Baker's cyst is a well-defined mass that consists of synovial fluid enclosed by the synovial wall and is located in the popliteal fossa. US is the gold standard in initial evaluation, definition of the cyst's clinical aspects, and differential diagnosis from other causes like meniscal cyst, popliteal artery aneurysm and soft tissue tumors. Sonography indicates a hypoechoic or anechoic formation that may contain debris or clots. Doppler analysis is also useful in order to exclude other clinical entities that demonstrate flow within the cavity (popliteal artery aneurysm, tumor).[21]

Abscess

US has been shown to be increasingly useful for abscess diagnosis, although clinical examination could provide information about the position and the size of a lesion it is difficult to distinguish different pathologies. Its high resolution and the ability to perform dynamic examination can allow for accurate differentiation between cellulitis and abscess, which can be challenging even for the most experienced physician. Depending on the location, the abscess can appear as an anechoic or hyperechoic spherical collection of echogenic fluid. There may be an echogenic capsule, but the borders are often poorly defined. During compression with the transducer, movement or swirling of the abscess content might be visible, while Doppler imaging reveals hyperemia in bordering tissues.[22]

Foreign Body

US is the preferred imaging modality for suspected superficial foreign bodies in children because of its ease of use, low cost, and lack of ionizing radiation. Using a high-frequency linear transducer, foreign bodies such as wood, plastic, or glass appear brightly echogenic [Figure 3b]. In the case of inflamed neighboring tissues, Doppler sonography depicts the foreign body as a bull's eye sign because of the increased surrounding vascularity.[23]

Hemangioma

Hemangiomas are vascular neoplasms that are divided into two categories. Infantile hemangioma, being the most common type, can be detected with US, but sonographic imaging depends on the stage of its evolution and may appear hyperechoic or hypoechoic. Congenital hemangiomas when examined with B-mode US are more heterogeneous. In both cases, color Doppler revealed an immense vascular density and blood flow.[24]

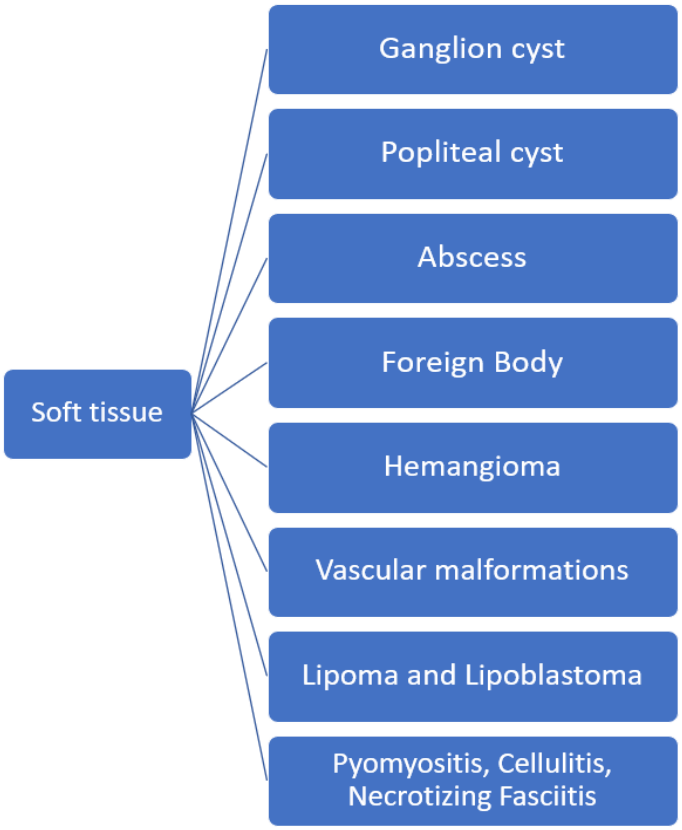

Diagram 2. Ganglion cyst

Vascular malformations

Vascular malformations include but are not limited to capillary, venous, lymphatic and arteriovenous malformation. Capillary malformations are usually superficial and do not cause any discomfort for the patient except esthetic implications. Sometimes they might be associated with other diseases or syndromes. During US examination, they appear as a skin and subcutaneous thickening versus contralateral healthy side.

Venous malformations have a very diversified appearance, they might be deep or superficial and are always compressible and soft. US can reveal well-margined masses that look like a "sponge-like" structure. Usually, they are hypoechoic compared to surrounding tissues.

Regarding lymphatic malformations, the most common lesion is macrocystic lymphatic malformation which appear as many different in size cystic formations divided by thin hyperechogenic septa. The cystic spaces' echogenicity is related to the presence of blood or infections, otherwise they appear anechoic.

Arteriovenous malformations need to be differentiated from hemangiomas because they are both high-flow lesions. Sonographically, it is possible to appear as a hypoechoic

subcutaneous lesion or an amorphous mass that can only be detected with color Doppler. The spectral Doppler analysis shows venous vessels with a higher flow velocity than hemangiomas.[24]

Lipoma and Lipoblastoma

Lipomas and lipoblastomas are benign tumors composed of adipocytes, the first of which is the most common soft tissue tumor, presenting in adulthood as a soft pain-free mass in the trunk or proximal extremities. On the other hand, lipoblastomas may present as a rapidly increasing mass in the extremities or trunk. Both pathologies should be distinguished from angiolipomas, epidermoid cysts and liposarcomas. US examination can reveal a wide range of appearances depending on the fat ratio. Lipomas frequently appear as hyperechoic, hypoechoic, isoechoic, or mixed solid masses; they also tend to display no acoustic shadow and no to minimal color Doppler flow. Lipoblastomas have a sonographic image similar to lipomas, with distinct outlines, internal cystic spaces, and are mainly hyperechoic.[25]

Pyomyositis, Cellulitis, Necrotizing Fasciitis

Pyomyositis refers to muscle infection, commonly occurring in the pelvic region, and is often induced by Staphylococcus aureus. During the first phase (phlegmonous) US, edema with intermittent hyperechoic muscle fibers, hypoechoic septa, and hyperemia, while the next phase (suppurative) Doppler sonography depicts fluid collection or abscess enclosed in a dense hyperechoic and hyperemic wall. Although the role of MRI in diagnosis is undeniable, US offers a more cost-effective method.[26]

Cellulitis is an infection of the skin and subcutaneous tissues, usually caused by Staphylococcus aureus and Streptococcus pyogenes. Clinical examination provides information regarding the location, size and tenderness of the affected area. US examination can reveal fluid collection with high echogenicity of the subcutaneous fat tissue and low acoustic transmission with hypoechoic filaments between hyperechoic fatty lobules.[22]

Necrotizing fasciitis (NF) is a severe, but potentially life-threatening, soft tissue bacterial infection, and its diagnosis can be challenging, especially in the early stages. MRI, bloodwork and clinical examination could provide helpful information at later stages. However, the utilization of US can be of great help in the early diagnosis of NF by identifying two main features. First, a hyperechoic focus just below the fat with posterior acoustic shadowing that corresponds to gas bubbles and second anechoic regions below the thickened fascia that represent fluid collection.[26,27]

4. Tumors and tumor-like lesions

Neurofibroma

Neurofibromas (NFs) are rare benign peripheral nerve tumors that can occur in different body locations. This type of tumor arises from a nerve sheath that obstructs its function. US examination revealed a hyperechoic mass filled with hypoechoic nodular or tubular structures. An experienced surgeon could distinguish between solitary and diffuse lesion. Doppler sonography often shows blood flow due to increased vascularity around the NF. Neuromas appear like round to ovoid, well-defined, hypoechoic lesion and schwannomas as well-circumscribed masses which displace adjacent structures without direct invasion.[28]

Osteochondroma

Osteochondroma is a benign chondrogenic lesion derived from aberrant cartilage from the perichondral ring and accounts for the most common benign bone tumor. X-ray imaging is the primary imaging technique used for diagnosis. However, US is helpful in estimating the size of the cartilage cap, which appears to have low echogenicity. An additional advantage of US is its ability to measure and evaluate cap thickness, which is usually thin for benign exostosis and thick for malignancy.[29]

Ewing's sarcoma

Ewing's sarcoma is a rare type of cancer that affects bones or tissues around bones, with most cases occurring between the ages of 10 and 20 years. Despite the fact that plain radiography is the primary imaging technique used, US can sometimes be of great importance for providing the diagnosis, especially when malignancy is not suspected. Sonography can show a hypoechoic soft tissue mass with a sunray pattern of periosteal reaction along the diaphysis of the bone combined with positive color Doppler, demonstrating increased internal vascularity within the soft tissue mass.[30]

5. Apophysitis

Osgood-Schlatter Disease

Osgood–Schlatter disease refers to traction apophysitis at the level of the tibial tuberosity, with a high prevalence in male athletes between 10 and 14 years of age. The current theory regarding the etiology is the repeated traction over the tubercle, which leads to micro-tears, fractures, and inflammation, resulting in anterior knee pain, swelling, and tenderness. US examination can depict the same anatomic abnormalities as plain radiographs. Specific findings, such as inflammation of the patellar tendon and bursa, swelling of the unossified cartilage, and irregularity of the ossification nucleus with internal echogenicity, can confirm the diagnosis [Figure 3c].[31]

Sever's Disease

Sever's disease, also known as calcaneal apophysisis, is a common cause of heel pain in adolescents. It is commonly seen in immature athletes participating in running and jumping sports, and the exact etiology is unknown. However, traction forces generated by the plantar fascia and the pull of the gastrocsoleus complex, combined with repetitive microtrauma during gait, seem to be the predominant theory. Similar to Osgood-Schlatter disease, US can show fragmentation of the second ossification center, combined with Achilles' tendinitis and retrocalcaneal bursitis. Moreover, according to Hosgören et al., sonography can also be utilized as a follow-up monitoring tool to avoid unnecessary ionizing radiation.[32]

6. Joint Effusion

Septic arthritis

Septic arthritis (SA) is a bacterial joint infection usually caused by Staphylococcus aureus and is most commonly located in the hip joint. SA is considered a surgical emergency and requires prompt recognition and urgent surgical irrigation and debridement followed by intravenous (IV) antibiotics. If not detected early or left untreated could lead to serious complications and long-term disability. The most common clinical aspect of septic arthritis is joint effusion. US is known to identify even small-scale joint effusions (1–2 mm) that appear hypoechoic or anechoic. Although sonography cannot differentiate between a septic and a sterile effusion, it can be used not only to identify the effusion but also to guide the aspiration. Although there are few studies that have tried to quantify effusions, it seems quite difficult and inaccurate since fluid can move_around when the examiner applies a little force around the affected area. However, it is easy to distinguish effusion from synovial thickening since the first one produces an anechoic area and the second a hyperechoic area that represents the thickened synovium. Combining US findings with clinical and laboratory findings can help physicians diagnose and treat SA successfully and uneventfully.[26,33]

Transient synovitis

Transient synovitis (TS) is an acute inflammation of the synovial stratum that occurs mainly in children aged 4-10 years. The hip joint is mostly affected and can be triggered by different factors, such as viral infection, trauma, and allergies. In children with a history and physical examination suspicious for TS, sonography is the preferred imaging technique because of its high sensitivity to accurately detect intracapsular effusion. It is difficult to distinguish TS from SA, but infection can be ruled out if effusion is absent [Figure 3d]. During the examination, the patient must be in the supine position and the hip in a neutral position; however, in most cases, the patient prefers to hold it in external rotation. Kocher's criteria combined with US-guided aspiration can provide valuable help to exclude SA and confirm TS.[34]

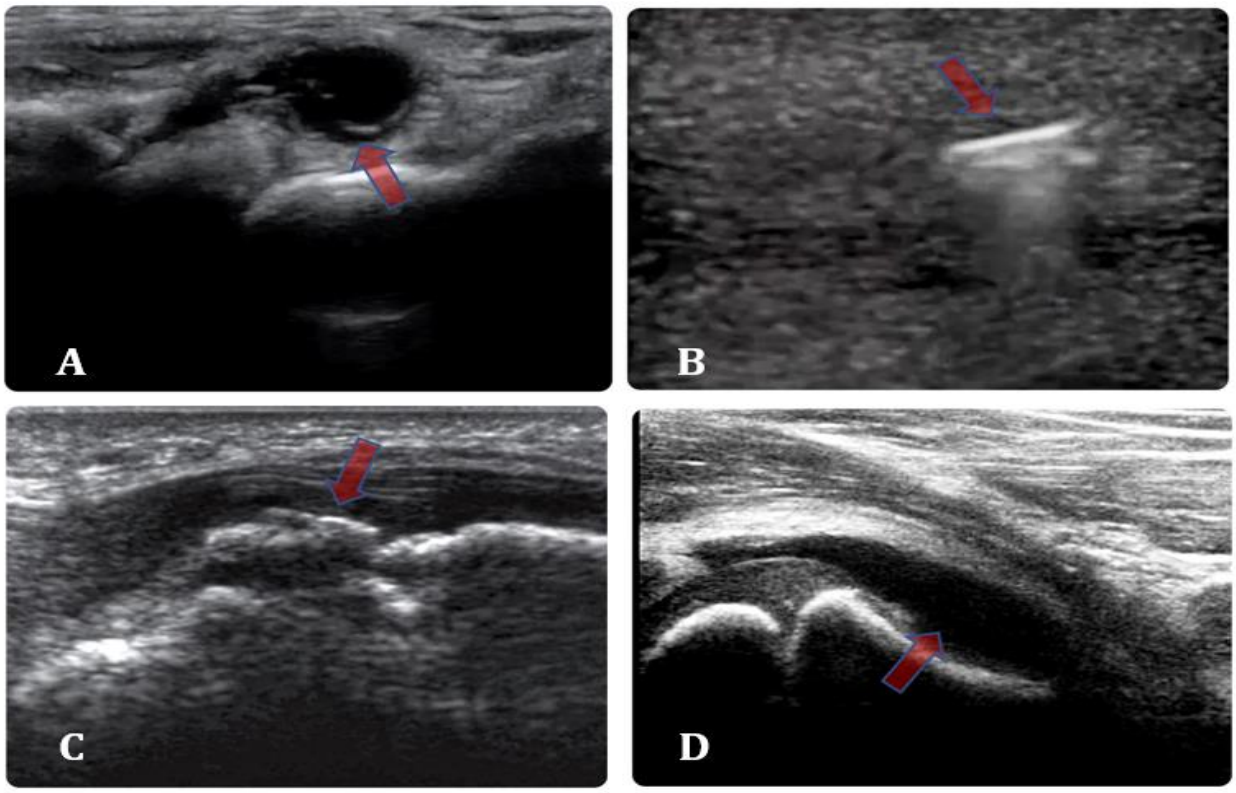

Figure 3. Dorsal wrist ganglion in a 14y old boy [figure 3a] foreign body (glass) in plantar aspect of the foot in a 6y old boy [figure 3b] Osgood Schlatter disease in a 12y old boy [figure 3c] Left hip effusion (diagnosed with transient synovitis of the hip) in a 5y old girl [figure 3d]

Juvenile idiopathic arthritis

Juvenile idiopathic arthritis (JIA) refers to a wide range of idiopathic inflammatory arthritis affecting the pediatric population, lasting six weeks or longer with unclear etiology. However, a combination of genetic and environmental factors seems to play a vital role in this abnormal immune response. JIA is a diagnosis of exclusion, and its course is highly unpredictable. Patients with JIA can be classified into different subtypes, with miscellaneous clinical features and disease severity. US plays a significant role in the imaging of JIA by detecting intraarticular and subclinical synovitis such as joint effusion, synovial thickening, synovitis, tenosynovitis, enthesitis, and bone erosion. Joint effusion appears as an anechoic formation correlated with the

surrounding structures. Synovial thickening and synovitis resemble a dense hypoechoic mass, in contrast to the surrounding tissues. Tenosynovitis is characterized by low or no echogenicity, depending on the presence of fluid. Ultrasonographic features of enthesitis include hypoechoic areas at the tendon root, with or without focal changes. Additionally, color Doppler examination, apart from showing synovial hyperemia, seems to be a widely used technique for follow-up of steroid injections, reflecting disease activity. Lastly, based on JIA criteria, oligoarthritis refers to "up to 4 joints involvement" compared to polyarthritis which involves >4 large joints. Therefore, US can be a useful tool in finding the affected joints in JIA and help classify it accordingly.[35]

Subperiosteal effusion in osteomyelitis

Pediatric osteomyelitis (OM) occurs when a bacterial infection from a remote part of the body spreads to the bone, with dissemination via the blood being the most frequently described in children. Although MRI is the gold standard for the prompt diagnosis of osteomyelitis due to its excellent anatomical detail, high sensitivity, and specificity for detecting early infection, US can be useful. US can reveal soft tissue or subperiosteal collections where osteomyelitis is suspected; however, MRI will still be required for a more thorough assessment. Subperiosteal elevation due to abscess can be recognized during US examination; the dynamic nature of sonography can also help with guided aspiration. Additionally, color Doppler can reveal areas of hypervascularity around the affected bone. Moreover, acute osteomyelitis is recognized by elevation of the periosteum by a hypoechoic layer of purulent material. In chronic osteomyelitis, US can also be used to assess involvement of the adjacent soft tissues. Soft tissue abscesses related to chronic osteomyelitis are identified as hypoechoic or anechoic fluid collections, which may extend around the bony contours. Finally, cortical erosions can become apparent on US.[36,37]

7. Femoral Acetabular Impingement

Femoral acetabular impingement is a syndrome involving structural abnormalities in the femoral head and/or the acetabular rim (CAM, pincer, CAM-pincer lesions), which can lead to pain, hip dysfunction, and subsequent osteoarthritis. MRI and X-ray are widely accepted methods for diagnosing femoral acetabular impingement; however, sonography seems to be a simple and inexpensive method for assessing CAM-type femoral acetabular impingement. It is not attainable to address the pincer component with US, additional imaging may be required for a careful evaluation of Femoral Acetabular Impingement. The information gained during US scan by employing parameters from MRI, such as the alpha angle, anterior head-neck offset, and anterior femoral distance, offers an easy and quick method for the early diagnosis of CAM-type femoral acetabular impingement.[38]

8. US guided musculoskeletal procedures

Aspiration

US, in addition to being an excellent diagnostic tool. can help physicians aspirate fluid in patients with different pathological backgrounds. Aspiration is a relatively quick and inexpensive way to further investigate fluid collection, with subsequent analysis of the fluid, which is a critical component in diagnosing a variety of pathological conditions such as JIA, SA, and OM. US provides an efficient and safe method for real-time visualization of the needle during the procedure. In this way, not only is the damage to nearby structures minimized, but the physician can achieve excellent tolerance with extremely rare complications from the patient's perspective.[39,40]

Injections

Over the past years, US-guided injections have become increasingly popular for both diagnostic and therapeutic treatment of a variety of problems. The use of US has significantly improved the accuracy of the injection of hyaluronic acid, corticosteroids, and biological therapies such as platelet-rich plasma (PRP) and stem cells. In addition, US is of high importance during joint aspiration, especially when the physician wants to rule out infection. US-guided injections allow the practitioner to visualize the needle in real time as it enters the body, avoiding structures such as vessels and nerves, and it has been shown to be less painful than blind injections.[41] in children with cerebral palsy, botulinum toxin (BOTOX) injection has been proven effective for reducing muscle overactivity. Thus, US-guided BOTOX injections can offer a practical and effective method for injection into proper points of certain muscles. The injection should be performed between the neuromuscular junction to increase the effectiveness of the treatment by inactivating some of the fusion proteins that are essential for cellular function. Additionally, correct placement of the needle within the muscle is of paramount importance to avoid adverse effects.[2,41,42]

Biopsy

Soft tissue tumors are uncommon. However, their diagnosis is challenging. In the vast majority, biopsy is the preferable method to allow a reliable histological diagnosis. US-guided biopsy has equal accuracy to open biopsy, avoiding the potential complications of the surgery. Thus, correct placement of the biopsy needle can be ensured to avoid damage to blood vessels and nerves. Regarding bone tumors, US-guided biopsy can be an alternative technique in a selected group of patients (surface lesions and aggressive tumors that have extended through the cortex) when compared to open biopsy.[43,44]

Foreign body removal

Foreign body removal can be challenging, especially when it consists of materials such as ceramic, wood, and plastic that cannot be shown on plain radiographs. Usually every soft-tissue foreign body appears hyperechoic at first. Wood becomes less echogenic over time. Glass is radiopaque on sonography. Metallic objects like sewing needles also appear opaque and with a bright echo. US guides the removal of a foreign body in real time. This is very useful especially in

deep dissections when the object could be displaced during exploration of the wound. For this reason, US provides excellent detection and localization of soft-tissue foreign bodies. Having the advantage of depicting all types of materials, US can be a valuable tool for removing a foreign body and guiding the entire percutaneous procedure, which can be completed through a small incision in the skin.[45]

Peripheral nerve blocks

Nerve blocks have traditionally been performed using surface anatomy-based landmarks and nerve stimulation that do not allow for the monitoring of the disposition of the local anesthetic. US can offer numerous advantages during the procedure, such as direct visualization of the anatomy, detailed guidance for the needle pathway to the nerve by avoiding nearby structures, and, finally, real-time visualization of local anesthetic solution delivery to confirm proper distribution. The combination of these elements can increase the success rate of the process and improve patient safety. For example, success rate of ilio-inguinal and ilio-hypogastric nerve block with US guidance was 96% intraoperatively and 94% postoperatively versus 74% and 60% intraoperatively and postoperatively respectively when using nerve stimulation or external anatomical landmarks.[46]

9. Limitations of ultrasonography

US is a safe, radiation-free, and non-invasive imaging technique. However, its disadvantages include dependence on a skilled operator and a long learning curve. Although recent studies have demonstrated excellent results in pediatric fracture diagnosis, sound waves are not able to pass through the bone surface, making the imaging of inner bone structures unattainable.[47] similarly, the majority of intra-articular structures cannot be adequately displayed because of the lack of an acoustic window. US examination is very patient-interactive and subjective; it is easy for the inexperienced to produce inaccurate results.[4,48] Therefore, orthopedic surgeons should be aware of both the abilities and limitations of this unique and radiation-free imaging modality and use it accordingly as the "orthopedic surgeon's stethoscope"

Discussion

US, due to its non-invasive nature, is a helpful diagnostic tool in pediatric orthopedics. US is superior at the same points when compared to other diagnostic methods, such as X-rays, CT, or MRI. For example, US does not use radiation such as X-rays and CT. In addition, US examination is fast and is applied in claustrophobic patients, in contrast to MRI. Moreover, with the new technological achievements, US is mobile, lightweight, and easy to use at the bedside (POCUS).[1]

US could assist in the diagnostic procedure in a variety of different pathologies. In the trauma section, we describe the use of sonography for many different types of fractures. An experienced orthopedic surgeon could diagnose long bone fractures, radial neck fractures, and other types of fractures using US. Thus, many X-rays will be avoided, diminishing the radiation to which patients are exposed. In addition, the soft tissue near the fracture could be assessed for additional damage.[1-4]

Developmental anomalies can be identified using sonography. US is the gold standard for diagnosing developmental dysplasia of the hip.[17] In addition, US examination is able to detect developmental dysplasia of the hip with accuracy regardless if the physician uses the static or the dynamic technique.49 Congenital dislocation of the patella US not only contributes to diagnosis but also provides vital information about the anatomy of the area to the orthopedic surgeon.[19]

The use of US for diagnosing soft tissue pathologies could be highly beneficial for orthopedic surgeons. In many pathologies, such as popliteal cysts, US is the gold standard.[21] Sonography could be helpful in diagnosing NF in a potentially deadly situation.[26,27]

In addition, many tumors and tumor-like lesions are diagnosed using US. Neurofibroma, osteochondroma, and Ewing's sarcoma are some of them.[28-30]

Some diseases such as Osgood-Schlatter and Sever's disease require an extended follow-up period. US is perfect in this situation because it has no radiation; it is fast and easy to use. Numerous joint pathologies such as septic arthritis, transient synovitis, juvenile idiopathic arthritis, and subperiosteal effusion in osteomyelitis can be diagnosed and followed up with the supplementary use of sonography.[33-37] Although US is not the gold standard for femoral acetabular impingement diagnosis, its non-invasive nature and low cost make it a useful tool.[38]

US is not only a powerful diagnostic tool, but also a useful tool for MSK procedures. Due to US mobility, low cost, and radiation-free nature, sonography is ideal for guiding aspirations, injections, biopsy, foreign body removal, and peripheral nerve block. With the use of US, these procedures are more effective with fewer complications.[39-46] US value in pediatric patients is visualized in [Table 2]. Due to US advantages compared to MRI, X-rays and computed tomography scan, POCUS is used to an increasing extent as a diagnostic tool for different orthopedic pathologies.[50]

Table 2. Value of the US in pediatric patients

No ionizing radiation	In comparison with X-rays or CT-scan
Cost-effectiveness	In comparison with CT-scan or MRI
Available at bedside	US is mobile, lightweight, and easy to use at the bedside
No need for sedation/ well tolerated	Sedation is needed for CT-scan or MRI if the pediatric patient cannot cooperate
Dynamic technique	It is possible to reveal several pathological conditions during patient's movement

Table 2. Continued

Comparative	Comparisons between healthy and affected side when possible
Bedside interventions	Aspiration, Injections, Biopsy, Foreign body removal, Peripheral nerve blocks
No adverse effects	No adverse effects were reported when US were used for diagnosis and guidance

Conclusion

US is increasingly being used in clinical practice in pediatric orthopedics for many reasons. Sonography is a fast, low-cost, mobile, non-invasive, and non-radiation diagnostic tool. It is also extremely useful for MSK procedure guidance. US in experienced hands is like "orthopedic surgeon's stethoscope".

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