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Basics, principles, techniques and modern methods in paediatric ultrasonography

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ABSTRACT

Ultrasonography (US) is the mainstay of paediatric Radiology. This review aims at revisiting basic US principles, to list specific needs throughout childhood, and to discuss the application of new and modern US methods. The various sections elude to basic US physics, technical requisites and tips for handling, diagnostically valuable applications of modern techniques, and how to properly address hazards, risks and limitations. In conclusion, US holds vast potential throughout childhood in almost all body regions and many childhood specific queries – helping to reduce the need for or to optimize more invasive or irradiating imaging. Make the most of US and offerings a dedicated paediatric US service throughout the day, the week and the year thus is and will stay a major task of Paediatric Radiology.

1. Introduction

When talking about ultrasonography (US) as a diagnostic imaging method in infants, neonates and children, a few basic considerations have to be revisited in order to properly understand the needs and to adequately apply the method in the various age groups and conditions. This is particularly important as technical development has enormously increased US potential, but still – whichever method is applied – the basic physics remain the same and the respective needs and phenomena have to be understood to make the most of these US capabilities. The following will briefly address basic physics, technical requisites, instrumentation and handling, limitations and artefacts as well as modern US methods applicable to paediatric US.

2. Physics revisited

It needs to be remembered that most of US relies on echoes emitted by transducer, then being reflected by various tissue interfaces of different density. The intensity of the echo received by the same transducer crystals is used to calculate the brightness of the specific reflector, whereas the position and space is defined by the time sound needs to travel from emission to reception. This means that the US image on the screen is a calculated image and not a real photography which may lead to artefacts – intrinsically caused by the underlying assumptions and calculations. The received echoes can be displayed either in a linear graph displaying the altitude of the echo (A-Mode, the first method used – today practically not applied any longer) pr as a time–space relation using a graph describing motion of the targeted structure over time in a linear behaviour (M-Mode, still used in ophthalmology, echocardiography and some abdominal applications, such as assessment of ureteral peristalsis or diaphragmatic motion) (Fig. 1) [1]. The most widely used display is the so-called brightness mode (B-Mode) which displays the brightness of the echoes throughout an entire section; fast image update in a real time fashion provides a film-like presentation of a cross-sectional view of the imaged region. This technique heavily relies on reasonable frame rates (=image updates), made possible by the high speed of the sound in tissue that allows to very quickly cover the targeted area and modern computer processing power.

A range of phenomena occur during that travel of the US beam, which may interfere with image quality and phenomena. As resolution and penetration depend on the frequency applied, proper transducer selection needs to be based on the query-defined the area of interest and application – higher frequencies offer a higher resolution at less penetration which is ideally applicable to young children, infants and neonates, and to superficial structures, whereas lower frequencies are necessary for penetrating into deeper areas as needed for deep body compartments and older children as well as adolescence – at the cost of restricted resolution. This implies that for paediatric US a range of transducers usually is necessary, as one often has to cover all queries from head to toe in

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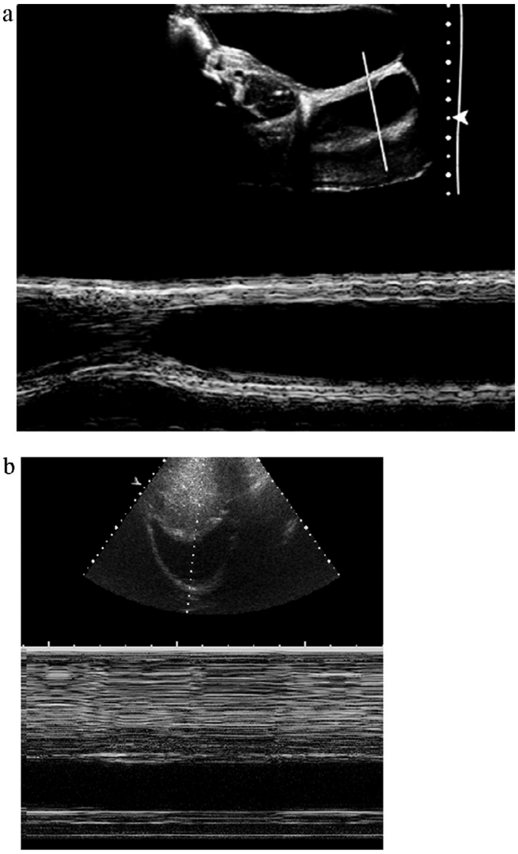

Fig. 1. M-Mode. Documentation of peristalsis in megaureter (a), and lack of respiratory motion in a traumatic liver and diaphragmatic injury (b).

large age group – from preterm neonates of about 400 g bodyweight to obese adolescents with up to 150 kg bodyweight.

Image quality is influenced by a variety of other factors such as the focus zone or time gain compensation (TGC). These aspects are essential for proper images and have to be constantly instrumented and updated during the investigation. Modern equipment offer auto-optimization options, but these only partially address the necessary changes adequately and cannot replace the examiners skill and instrumentation. Common mistakes include using only the upper third of the monitor instead of having the organ of interest in a proper scale ("remember: you bought the entire monitor, so use the entire one"), inadequate TGC adaption, wrong focus position, inadequate frequency and transducer selection, and inadequate output- and receive-gain manipulation (Fig. 2).

3. Technical requirements, child adapted environment, specific tips and tricks

Most modern US equipments offer several pre-set options which are very helpful to easily and quickly adjust the device towards the scanned region; having additional age-adapted pre-sets for each transducer is particularly helpful. TCG adaptation and flexible (multi-)focus options are essential for many applications, also Doppler sonography options. A range of transducers is necessary to cover all areas throughout the entire childhood: A high frequency sector (vector) probe for neonatal brain US and echocardiography as well as some chest applications, high resolution (multi-)frequency linear transducers possibly supplemented by high frequency micro-curved array for the infants abdomen (also very useful for the brain, and essential for US of the small parts, joints, musculoskeletal system and bowel), and low (multi-)frequency curved array for the other abdominal applications. For echocardiography in older children and transcranial brain US, lower frequency sector transducers may become necessary as well as low frequency curved arrays for obese children. With modern transducers stand-off pads (which sometimes may be useful) are usually not necessary – this can be replaced by liberal use of US gel. Proper documentation has become standard mostly using digital formats with DICOM compatibility. In children cine-loop is particularly helpful – the export of video clips is increasingly recommended, and scrolling through such a clip will allow capturing the most appropriate image for diagnosis and documentation. This applies not only for high-end devices but also for average equipment, as newer approaches coming from point of care developments (that rely on even non-medical, briefly trained staff to acquire to the US sweep over a defined area or acquiring a standardized 3DUS-volume that then is send to the central reading office for diagnosis) is being introduced particularly for low resource areas with poor health facilities and restricted access of e.g., the rural population to basic medical services. But this also is being discussed as an option for more developed countries to reduce healthcare costs and supplement shortcomings from an increasing need for presently unavailable trained medical staff. Therefore sophisticated electronic export, communication and storing options are becoming indispensable.

Due to the child's restricted co-operability a different handling is necessary: you need enough space also for helping and accompanying persons (nurses, parents and relatives...) as well as swaddling facilities, heater, toys and games, books, warm tea and a pacifier (potentially supported by some drops of glucose). The US gel can be warmed; however, hygiene precautions have to be taken to avoid bacterial or fungal growth. It is helpful to first relate to the child – basically trying to explain the procedure before starting an US investigation. The transducer then is handled gently and – particularly in infants and small children – a constant connection with the child's skin is usually welcomed as the procedure becomes more like a massage than an investigation, thus creating a cooperative patient and enabling a diagnostic examination. If positioning manoeuvers are necessary they should be performed slowly and gentle. Transducer movements also should be without any sudden change of position. If graded compression is used this should be applied gradually avoiding too much pressure in painful areas. If commands are used to improve US access, try to phrase them in a child's wording, such as, instead of "hold your breath" it often works better to have the child imaging "a deep dive in the swimming pool", or to ask to "show how big the belly can get after having visited your favourite restaurant". Additionally, particularly in the abdomen, US access can be gained by replacing the air/gas within gastrointestinal structures with some fluid that will allow sound penetration as well as assessment of patency, distensibility and intraluminal structures. This can be achieved by feeding a bottle of tea, in neonates sometimes by installing the fluid via a gastric tube, or by a gentle enema using warm saline for the colon (Fig. 3) [2–6]. Unconventional approaches such as a perineal access (to see structures of the lesser pelvis and the perineum, the urethra, the vagina, etc.) are usually nicely tolerated and significantly enhance US diagnostic capabilities for certain conditions (e.g. urethral pathology, anal atresia, US genitography) (Fig. 4) [7–9].

4. Modern techniques

As in adults many modern techniques have become standard for routine imaging also throughout childhood. Harmonic imaging – relying on the second harmonic response of the emitted