High-Frequency Ultrasound of the Nail

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Keywords

Imaging • Ultrasound • Skin • Nail • Anatomy

The nail is of functional and cosmetic importance and therefore constitutes a sensitive area for most patients. Clinical diagnosis may also pose a challenge, but the usual diagnostic recourse to biopsy is influenced by the risk of subsequent scarring and risk of lasting nail deformities. In addition patients would often prefer noninvasive diagnostics. High-frequency ultrasound imaging is therefore a suitable and generally available technique for nail studies.

1 About Ultrasound

Ultrasonography is real-time noninvasive diagnostic imaging based on a principle of inaudible sound waves that are transmitted through the material examined and the analysis, of the subsequent reflected echoes, which is converted to a two-dimensional visualization of the material. The sound waves are characterized by their amplitude, propagation speed, and frequency. Differences in the reflected sound waves are caused by the different acoustic impedances of different substances changing the amplitude or propagation speed of the sound waves. Generally hard or dry materials and air have higher impedance shown as (hyperechoic) bright areas, whereas fluids have low impedance and are shown as (hypoechoic) dark areas (Wortsman and Jemec 2006; Bitsch et al. 2011).

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In standard grayscale mode (B-mode) ultrasound, the frequency is constant. High frequencies generally create high resolution and shallow penetration, whereas low frequencies yield low resolution but deeper penetration.

When analyzing changes in the frequencies of reflected echoes, it is possible to visualize movement of material, most often flow of liquids through Doppler ultrasound. This is often shown as a blue to red color overlay (color Doppler mode) or as monochrome overlay (power Doppler mode) on the B-mode ultrasound visualization. Flow in selected areas of the examined material can be further explored both visually and auditory by using spectral Doppler mode.

A static computer-assisted three-dimensional visualization is also a possibility in many ultrasonographic devices enabling an overview of complex lesions such as the nail apparatus (Bitsch et al. 2011).

2 Technical Features/Handling

Many different ultrasound devices are marketed, and modern equipment is readily available in many hospitals that provide a wide range of capabilities, which include the technical capability to image the skin and the nail. The quality of imaging equipment has generally improved, prices have decreased, and handheld devices are now widely available and affordable.

The ultrasound device is basically a computer connected to specialized transducer containing the piezoelectric crystals. As in personal computers, big processors and screens with high numbers of pixels provide better images. High-frequency transducers usually linear or compact linear probes (hockey stick shaped) are commonly used for studying the skin and nail (Bitsch et al. 2011).

These variable frequency probes range in their upper frequencies between 15 and 22 MHz; however the same probes may also work in lower frequencies that range from 7 to 8 MHz. Therefore the operator may set the parameters of the machine according to the depth of the anatomical structure under study. This range will suffice in both appropriate depth and high resolution, with higher frequencies being more suitable for the imaging of the nail apparatus.

An abundance of gel should be used to discriminate all the layers of the skin or nail from top to bottom. As opposed to internal organs, a minimum of pressure should be applied to avoid thinning out layers of the skin or closing vasculature.

The digit under examination should be as extended as possible to ensure recognizable landmarks during scanning. Longitudinal and transverse planes should be scanned through. B-mode (grayscale), Doppler color flow, Doppler power flow, and (rarely) Doppler spectral analyses can be relevant regarding the nail (Wortsman and Jemec 2006; Wortsman 2013).

3 Anatomy/Acoustic Properties of the Nail

3.1 Anatomy of the Nail

The anatomy of the nail unit is well described. The surface anatomy consists of the nail plate, the proximal and lateral nail folds, the lateral nail grooves, and the eponychium. The nail plate itself can be described as convex both longitudinally and transversely – with a distal free margin, a hyponychium, a central nail plate, and a proximal lunula. Changes in the nail plate are described in ▶ Chap. 92, "Gene Expression and Genetic Evaluation of the Skin."

Beneath the nail plate is the nail bed. Proximally, underlying the lunula is the nail matrix and nail sinus producing the keratinocytes of which the nail plate consists and further distally the nail bed consists of a thin epidermis overlying a collagenous dermis and the distal phalanx.

The most prominent nerves and vessels in the digits run on the palmar side. Both the neural and arterial supply to the distal phalanx is primarily provided by palmar conduits; however the nail matrix is supplied from the dorsal arterial arcade. Clusters of arteriovenous shunts, glomus bodies, are found in the nail bed (Fleckman 2005).

The entheses of extensor tendons are found adjacent to the nail matrix.

4 Normal Nail Sonography

The different tissues of the nail have different densities and thus different echogenicities. The nail plate has a characteristic bilamellar structure with a central hypoechoic interplate space (Jemec and Serup 1989). See Fig. 1. The speed of sound in the nail plate has been determined at 2459 m/s, compared to the 1580 m/s estimated speed of sound in the skin. It is thought that the bilamellar structure reflects the water (35 %) distribution in the nail plate, with a dry outer compartment in which the speed of sound is 3103 m/s and a deeper more humid compartment in which the speed of sound is 2125 m/s (Jemec and Serup 1989).

Under the nail bed, it is possible to detect the hyperechoic linear bony margin of the distal phalanx. Proximally to the nail plate and in close proximity to the mail matrix, the insertion of the extensor digitorum tendon on the phalanx can be visualized. Low-velocity blood flow can be detected in the nail bed, usually close to the bony margin of the distal phalanx (Fig. 2). The

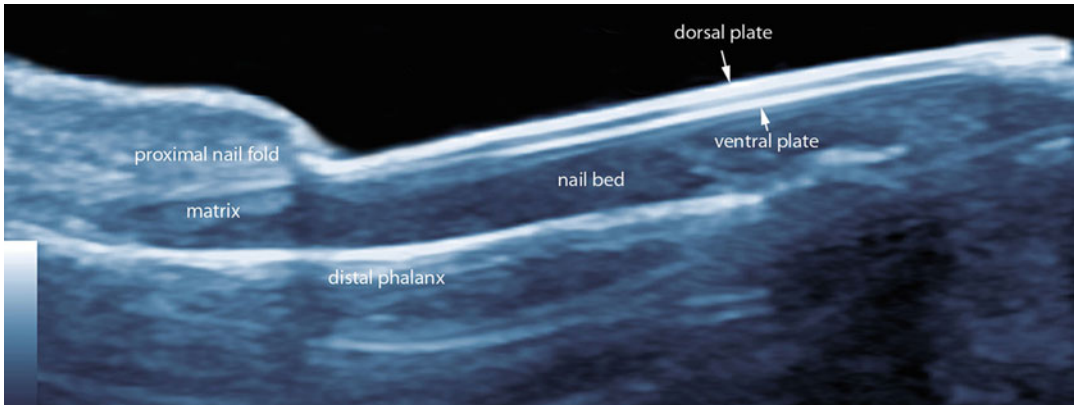

Fig. 1 Ultrasonography of normal nail plate (*grayscale*, longitudinal view) showing the different part of the nail unit

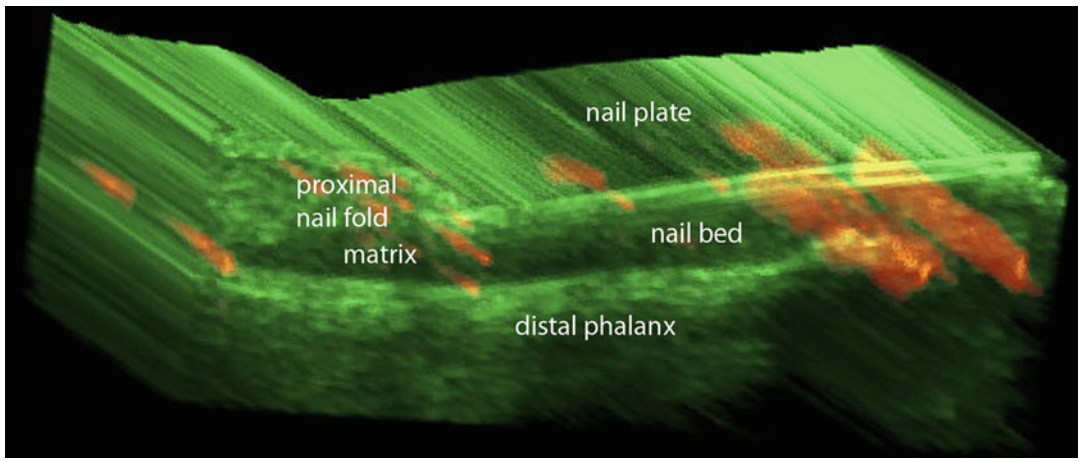

Fig. 2 3D power Doppler reconstruction of the nail unit (longitudinal view) demonstrates the vascularity (*red color*) within the nail bed

Table 1 Sonographic nail findings

Pathology	Typical findings
Alopecia areata	In alopecia areata, two thirds of patients have somewhat unspecific nail involvement, which however may precede scalp affection. Most often nail pitting and nail dystrophy are seen similar to nail changes in psoriasis. However, in contrast with psoriasis, usually the nail bed is hypovascular (Wortsman 2013)
Ichthyosis	Often nails are thickened and the hypoechoic thin layer between the dorsal and ventral plates is no longer discernible (Wortsman and Aranibar 2001)
Benign tumors	Glomus tumors – these benign vascular tumors are derived from the neuromyoarterial glomus and clinically present exquisite pain in the nail region. Sonographically, they appear as a hypoechoic well-defined nodule that commonly shows hypervascularity. Scalloping of the bony margin of the distal phalanx is a frequent associated finding (Wortsman and Jemec 2009)
	Onychomatricoma – seen as yellow bands along the nail. Sometimes added convexity can make the nail cone shaped. Often hypoechoic areas with hyperechoic spots or lines of the nail bed and interplate space are seen. The underlying bone is usually unremarkable (Soto et al. 2009)
	Keratoacanthoma – these squamocellular neoplasms can rarely occur in the nail bed. Appears as a well-defined solid mass with a central cystic/anechoic area surrounded by hypoechoic tissue and enhancement artifact. Can affect both nail plate and bony margin. With Doppler the tumor will show hypovascularity (Choi et al. 2007)
	Granuloma – a chronic proliferative inflammatory scarring reaction most often involving periungual tissue, but also nail bed or even matrix. Sonographically hypoechoic lesion without sharp demarcation. Increased nail bed thickness, corrugated upward skewed nail plates (Wortsman et al. 2010b)
	Verrucae – subungual warts are hypoechoic spindle-shaped elements resulting in thickened nail plates (Wortsman et al. 2010c)
Dermatomyositis	A telltale sign in prolonged disease is the calcinosis. Small epidermal fingertip calcium deposits visualized as hyperechoic deposits with pronounced posterior acoustic shadowing (Wortsman 2013)
Malignant tumors	Bowen disease – no early diagnosis is possible in Bowen disease; however in later stages an hypoechoic solid mass that erode the nail plate may be found (Wortsman 2013)
	Malignant melanoma – when arising from the nail matrix, it is typically seen as a dark-pigmented longitudinal stripe involving the lunula and the hyponychium. Early diagnosis by sonography is difficult, because pigments are currently not detected by ultrasound. Nevertheless, hypoechoic ill-defined areas and localized hypervascularity may be found. In later stages, a hypoechoic solid tumor can be seen (Wortsman 2013)
Onychomadesis	Onychomadesis is basically a Beau line with full separation, instead of an indentation. After nail growth arrest onychomadesis is seen. The nail plate separates from the matrix. Typically two unconnected hyperechoic nail plates are seen. Often the distal nail plate is somewhat thickened (Wortsman et al. 2010a)
Psoriasis	Psoriatic nail involvement is linked to psoriatic arthritis and severity of skin disease. Classic findings are thickened nail beds measured by the distance between the nail plate and the phalanx. Thickening of both plates and blurring of the ventral nail plate. In late disease even blurring of dorsal plate is seen as well. Corrugated nail plate can be seen
	Hypervascularity in the nail bed during active disease giving increased Doppler activity (Gutierrez et al. 2009)
Scleroderma	Vascular damage is in focus with nail pathology in scleroderma patients. Thickened nail beds with lower echogenicity and thickened nail plates with loss of interplate space. Commonly the nail bed shows hypovascularity (Wortsman et al. 2011)
SLE	Irregular nail beds and plates and hypovascularity are often seen (Wortsman et al. 2011)
Subungual abscess	Anechoic areas with acoustic enhancement and inflamed and thickened nail beds. Hyperechoic air bubbles may be present. Sinus tracts increasing the risk of joint affection or osteitis can be followed if present (Wortsman 2013)

skin surrounding the nail plate is almost devoid of fat, though in other ways no different from a normal skin sonography (Wortsman and Jemec 2006; Wortsman 2013).

5 Pathology/Applications

Diagnosing ungual, subungual, or periungual pathologies clinically is often difficult as the nail plate naturally prevents closer inspection. Similarly, the use of diagnostic biopsies through the nail or in the periungual area is often painful or unpleasant to the patient and potentially harmful as the nail matrix is easily damaged leaving the patient with a permanent defect in a cosmetically important area.

The convenience and the noninvasive dynamic nature of ultrasound enable the early diagnosis of common nail pathology. The use of this imaging method relies on an interpretation of basic sonographic tissue characteristics:

1. Inflammation: The inflammation causes dilatation of vessels and subsequent edema and possibly abscess formation. The vascular changes are best visualized using color Doppler or power Doppler, which shows hypervascularity and increased flow. Inflammation generally presents as associated hypoechoic areas. In older lesions a reactive thickening of the nail bed will often be seen.
2. Tumors: The sonographic image depends on the density of the tumor. When measuring tumors, using a standard procedure is therefore an advantage. Diagnostically, it is important to know the precise position of the tumor, size, composition, what structures are involved, and if it is hypo- or hypervascularized.
3. Abscess or cysts: Fluid-filled cavities with or without air appear anechoic and show no Doppler activity, but often enhancement artifacts, where underlying tissue appears hyperreflective.

A summarized review of nail pathologies as identified by ultrasound is given in Table 1.

6 Conclusion

High-frequency ultrasound of the nail can give valuable clues and support early diagnoses and is easy to use. Both rare and more frequent lesions can be diagnosed with ultrasound examination in context of the clinical work-up.

Sonography is not the same as, e.g., histology. It is not as detailed and does not allow the same detail of diagnosis, but it offers an important advantage over histology as it provides functional real-time information about the tissue as well. A prime example of this is the bilamellar images of the nail plate, where sonography reflects hydration which would otherwise not be seen. Similarly, the density and perfusion of tissue are readily available in ultrasound, but not in histology, making it an important imaging method for clinical manifestations in the skin.

The simple and dynamic nature of the sonographic examination and the ready accessibility compared to the, e.g., magnetic resonance imaging are important factors when choosing diagnostic methods. Lastly, sonography can offer a noninvasive window into the physiopathology of nail diseases.

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