Dermatology Ultrasound. Imaging Technique, Tips and Tricks, High-Resolution Anatomy

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Abstract: This article reviews the ultrasound (US) scanner setting, the examination methodology, and the anatomy of the skin. Dermatologic US requires frequencies of 15 MHz or greater and appropriate probe handling. The use of color Doppler imaging is mandatory, proven that it is set to detect slow flows. Trapezoid field of view, extended field of view, 3-dimensional reconstruction, elastography, and new microvasculature imaging facilities can help, if available. Operators must be aware of the adjustments and tricks useful to improve the image quality. High-resolution US allows detailed assessment of epidermis, dermis, subcutaneous tissue, and skin appendages. Differences exist according to patient age, sex, and body area. Appropriate knowledge of the anatomy is mandatory to image skin abnormalities.

Key Words: skin, ultrasound, Doppler, anatomy

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Objectives: After reading this article the learner should:

- Be aware of the technical and methodological requirements to optimally detect skin abnormalities, understanding the clues for improving the recognition of the cutaneous echtexture.
- Know the normal anatomy of the skin and the high-resolution ultrasound, Doppler, and elastography normal findings, also considering the differences between different body areas

In recent years high-resolution ultrasound (US) in dermatology is gaining interest among many different specialties, including radiologists, dermatologists, rheumatologists, and plastic surgeons. Color-Doppler US can image the skin in multiple planes and provide information in many clinical scenarios, varying from aesthetic medicine applications to skin tumors.[1–5] Importantly, the spatial resolution of US working with linear probes of frequencies of 15 MHz or greater allows a much higher definition of the skin than the one obtained with the current magnetic resonance imaging, computed tomography, or positron emission tomography-computed tomography devices.[6] However, proper scanner setting, standardized exploration methodology, and knowledge of specific anatomy are necessary.

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B-MODE EQUIPMENT AND SETTING

Dermatology US requires the use of linear or compact linear (hockey-stick) probes. Hockey stick-shaped probes represent a useful tool, particularly to study the face, fingers, and nails, as well as to scan the children.[7] Their comfortable shape and their small size may optimally adapt to the surface and avoid the generation of scattering artifacts.[8]

Probes working on frequencies between 15 and 22 MHz allow displaying the skin layers and its abnormalities with a sufficiently high resolution, enable differentiating structures of approximately 100 microns on the beam axis and 200 microns on the scan axis (Fig. 1).[9–11] Normally, the field of view (FOV) area nearest to the transducer is compressed for a length that depends on the quality and frequency of the transducers.[12–14] The use of a high frequency allows to put the skin within the near-field or Fresnel zone, which is the part of the US FOV with the best beam focalization, and consequently, with the highest spatial resolution. With transmission frequencies below 15 MHz, the spatial resolution is lower, and the images of the superficial layers are not reliable for discriminating alterations. The operator may try to improve the beam focalization of 7.5 to 13 MHz transducers in the most superficial part of the FOV by placing a copious amount of gel or a gel-pad spacer between the probe and the skin.[15] However, the use of transducers with a frequency less than 15 MHz is not encouraged.[10]

At high frequency, the spatial resolution increases but there is lower penetration. In the last decade, very high-frequency probes (30–100 MHz) have been commercially available and are approved to be used in humans. However, although these probes may offer exquisite images of the epidermis and dermis, their penetration capability is significantly limited (3 mm at 75 MHz and 1 mm at 100 MHz).[7,16,17] This means that the full exploration of the deep subcutis and the musculoaponeurotic layer is not possible and, for example, a skin cancer affecting deeper layers may be incompletely displayed. Therefore, a probe working on the upper range of frequencies between 15 to 24 MHz and 15 to 30 MHz is mandatory to perform dermatologic examinations.[10] Additionally, some very high-frequency systems use a fixed working frequency, are quite sensitive to motion artifacts, or may not allow a color Doppler scanning.[16] The use of these systems is mostly limited to specialized dermatology and research units.

Variable-frequency probes allow balancing between resolution and penetration and are incorporated in sophisticated and

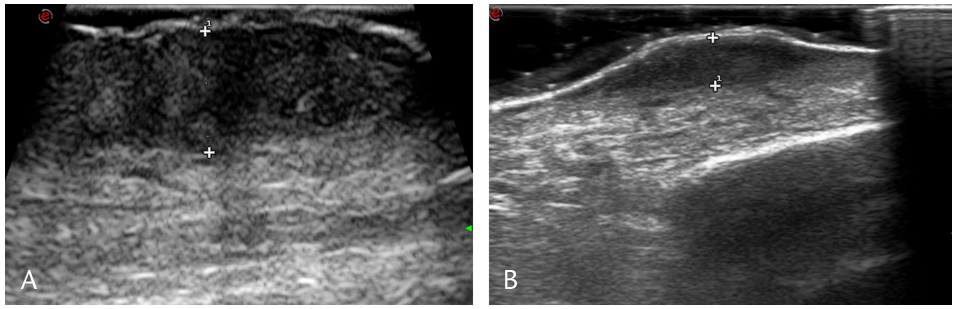

FIGURE 1. A 71-year-old man with a 4.6-mm-thick basal-cell carcinoma. A, The tumor is depicted with a high resolution when imaged at 22 MHz. B, Same tumor evaluated at 13 MHz.

expensive multichanneled scanners with powerful processors.[7] As a general rule, the operator may start with the lower frequency range and then move up in frequency to get details of the area of interest.[18] Ideally, 2 multifrequency linear probes should be available, one with a frequency range from 7.5 to 14 MHz and another one with an upper frequency of 15 to 24 MHz. The former transducer, given its higher penetration, is necessary to explore the muscle plane, the fascia, the subcutaneous layer, and the lymph nodes, whereas the latter one, owing to the higher resolution, is mandatory to scan the dermis and epidermis.[8,18–21] As an alternative, manufacturers are now commercializing transducers with a vast range of transmission frequency, even from 2 to 22 MHz. In this case, a single linear probe may be used for all the superficial applications.

The creation of a specific dermatologic preset in the machines is useful because so far, most of the devices are sold without a configuration for dermatology. Starting from this preset, the setting is modified during the examination accordingly to the ongoing findings and particularly to the depth of the area of interest.

Optimization of the location of the focal point or points is relevant, and it or they should be placed at the level or just below the level of the abnormality evaluated.[8,14] The gain can be increased to amplify the echoes but not excessively, avoiding the generation of artifacts. The time-gain compensation curve should be regulated accordingly to the depth of the abnormality evaluated. The depth of the FOV should focus on the area of interest and show the abnormal and normal tissues around the lesion, not just the anomalous zone. Electronic zoom can be useful if the operator wants to measure minimal distances. Additionally, the use of tissue harmonics may help because it can reduce imaging artifacts and improves resolution.[8] Finally, spatial compound imaging can increase the signal-to-noise ratio and decrease artifacts; therefore, it can improve image quality.[8,16]

EXAMINATION METHODOLOGY

The examination starts with a thorough inspection of the site to be examined.[9] Both the patient and the examiner must be in comfortable and stable position. Compared with other application fields of high-resolution US, the skin requires the probe to be held very close to its footprint. This allows to be very gentle in moving the probe, which will somehow float above the gel heap but, at the same time, be firmly held, to avoid motion artifact. The ulnar side of the operator hand holding the probe should rest on patient body. Positioning the fifth finger on top of the skin can provide further stabilization and act as a pivot point (Fig. 2).[7,14,22] As an alternative, the fifth finger can be extended and pointed over patient surface. An unaffected skin area, being contralateral or perilesional, should be used as a control for skin appearance and thickness, particularly in the case of inflammatory skin diseases [17, 18].

An abundant layer of gel, more than what is used in other US applications, allows obtaining the best focal point.[9] The removal of hairy areas is usually not necessary because the abundant gel will allow the hair to soften. Nevertheless, to detect lesions on the scalp, the displacement of the hair tract is essential, which can be done with a comb.[17] In the study of lesions with severe crusting or severe keratotic reaction, the gel may help to soften the hard layer; however, in some cases the removal of the crust or part of the keratotic reaction is needed.[23] Some water or the gel itself may wet these lesions before imaging. Sedation may be required in children younger than 4 years to avoid artifacts derived from movement or crying in the color Doppler study.[16] Chloral hydrate (50 mg/kg) can be administered orally 30 minutes before the examination.[16]

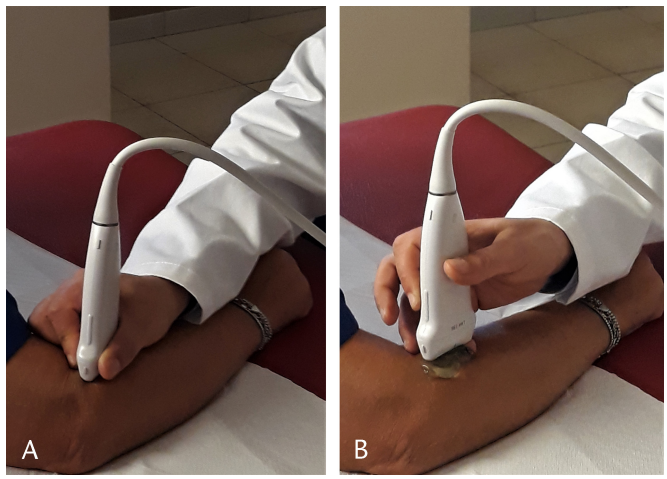

FIGURE 2. Appropriate use of the probe in dermatology ultrasound. A, The probe must be hold firmly, with the operator hand over the patient body. B, A large amount of ultrasound gel must be placed between the probe footprint and patient skin (please note that the operator hand has been raised to allow recognizing the gel heap).

As mentioned before, the use of a layer of gel optimizes sound transmission, decreases surface artifacts in the near field and provides an optimal display of the dermis and epidermis.[6,8] As an alternative, commercially available spacers (standoff pads) could be used.[15,24] These gel pads have advantages and disadvantages over the gel heap. Both modalities allow not only to optimize the beam focus but also to better adapt the flat linear or compact linear probe to some complex anatomical areas, such as the ear pinna and the area around the nose and eyes. It has been shown that spacers increase the detection rate of flows within very superficial lesions in comparison with direct contact between the probe and the skin.[24] Probably, this is because the spacer allows a better location of the focal point. The standoff pads may also provide a clean space on top of the lesion; nevertheless, they may potentially compress the tiny dermal vessels of the low flow vascular lesion. Therefore, a copious amount of gel may be enough to observe well the most superficial layers and blood flow, and direct contact of the probe or the excessive pressure of the skin surface should be avoided.

Particularly for very superficial abnormalities, the probe must be held gently but with a firm hand. The contact of the transducer with the skin should be as smooth as possible to avoid compression of the anatomical structures below and incorrect measurements.[9] Excessive pressure of the transducers may modify the image, particularly in the uppermost portion of the FOV, flattening the abnormalities and causing an underestimation of the lesion thickness. Unnecessary pressure may also decrease the number of flow signals at color Doppler imaging.[7,25] Areas, such as the female breast and the external genitals, should be covered,[14] and the use of nonsterile gloves is desirable for not sliding the hand within the gel.

Scans are obtained with the probe in at least 2 perpendicular axes, longitudinal and transverse, and then more axes such as transverse-oblique, and longitudinal-oblique scans are taken, according to the axis of the lesion. When scanning the hair follicles, for example in the scalp, it is necessary to follow the main axis of the hairs.[6,17] In the study of the face, such as in aesthetic applications, the patient will lay supine, with the head perfectly parallel to the bed (Frankfurt line perpendicular) and the mouth and eyes closed. Scan planes will take into consideration the orientation of the fibers of the orbicularis muscles of the eyelids and the lips. Some applications require the isometric contraction of specific facial muscles which can help to recognize the regional structures better.

COLOR-DOPPLER EQUIPMENT AND SETTING

The use of color Doppler is mandatory in almost all dermatologic applications.[25–28] The amount of vascularization of skin abnormalities can be subjectively categorized into absent, low, moderate, and intense, whereas the flow signals distribution is classified as perilesional, intralesional peripheral, intralesional central, or mixed. Spectral curve analysis is desirable but not mandatory, with the exception of vascular abnormalities that always require a quantitative Doppler sampling.[18] If the spectral analysis is performed, the maximum velocity of the vessels must be given in the report, usually in cm/s. If needed, the resistive index can be also be automatically calculated by the scanner.[8]

The color Doppler transmission frequency should be above 6 MHz, ideally between 7 and 14 MHz, according to the depth of the abnormality investigated.[8] The focus of the color Doppler needs to be located at level of the lesion, or immediately below.[8] The color Doppler setting should be optimized to detect very slow flows.[15,16,18,19] The recommended configuration for dermatologic examinations includes the use of a low pulse repetition frequency and the selection of a low wall filter.[16] Given its higher sensitivity to slow flows, the power-Doppler mode could be preferable, but this depends on the performance of the scanner available.[16,27]

Usually, given the high sensitivity of current color Doppler systems, there is no need to enhance the flow signal using an intravenous injection of contrast media.[21] In vascular tumors, sometimes, the problem is not to increase flow signals, but to decrease the noise, by modifying the gain, filter, or pulse repetition frequency. This will allow making the whole vascular architecture of the tumor more understandable.

OTHER TECHNICAL CONSIDERATIONS

Trapezoid scans, which means the widening of the deep part of the usually rectangular FOV of the linear transducers, are useful to display large, deep lesions or to measure the distance between multiple lesions.[15] Real-time, extended FOV scans, obtained by a freehand movement along a given plane and electronic merging of the frames into a single, wide image, can be effective to show the extent of a large lesion, to better display multiple lesions, and to measure the distance between the abnormalities and neighboring anatomical landmarks or critical structures (vessels, bony promontories, etc.).[8,16,29]

Volumetric scanning is useful, although not mandatory. If available in the scanner, this allows obtaining 3-dimensional (3D) reformatted images on planes not directly accessible to the probe and 3D, color-filtered reconstructions of the abnormalities (Fig. 3).[22] Three-dimensional reconstructions are commonly performed for highlighting the features of the lesions by typically making 5- to 8-second sweeps. Optimal display of skin layers is obtained from multiplanar reconstructions. Accurate measurement of lesion volume is also achievable.[8,16]

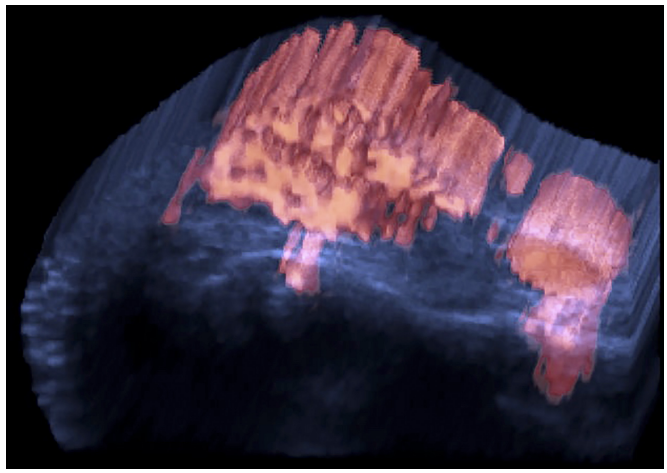

FIGURE 3. Three-dimensional reconstruction of the power Doppler scan of a nasal telangiectatic granuloma.

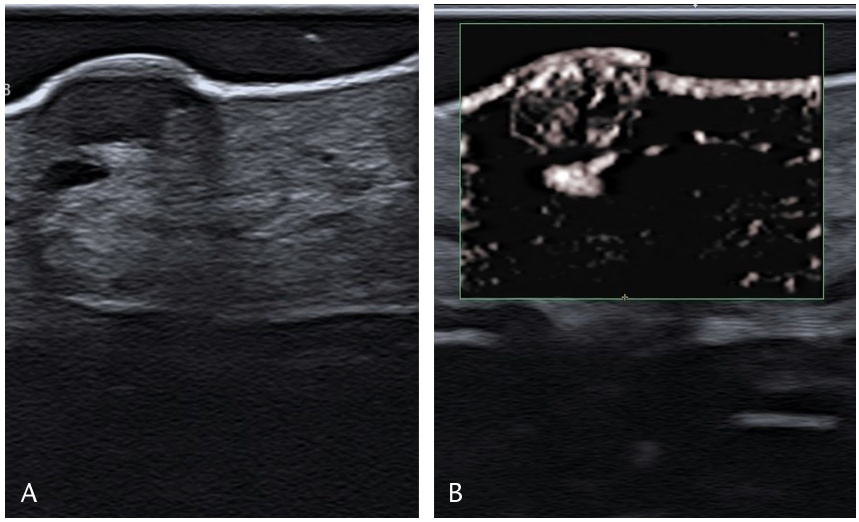

FIGURE 4. Dermis metastasis from Kaposi sarcoma. A, The B-mode image (24 MHz) optimally displays the hypoechoic nodule, relatively homogeneous and well-defined, below the hyperechoic epidermis line. B, New microvasculature techniques, in this case Superb Microvascular Imaging from Canon, allow exquisite depiction of the small intratumoral vessels.

New tools for microvasculature display have been developed recently by many manufacturers.[30] These applications work with a high frame rate and consequently tend to be more sensitive for detecting slow flow in comparison with color or power-Doppler; therefore, if available, their use is desirable (Fig. 4).

The use of elastography in dermatology represents an exciting potential, particularly in the fields of skin aging, skin tumors, and fibrotic conditions, but to date their evidence and experience in dermatology are still limited and controversial.[27,31–34]

Regarding the use of contrast-enhanced US in dermatology, there are very few reports. Contrast-enhanced US could be useful to evaluate the vascular activity of tumor and inflammatory lesions, both before and after treatment, but nowadays, this is not used in the clinical practice.[35] Probably, the availability of microbubbles exploding at higher frequencies is needed to study skin entities.

Skin Anatomy at High-Resolution US

The skin is composed of 3 functionally connected layers, namely, from top to bottom, the epidermis, the dermis, and the hypodermis (subcutis or subcutaneous tissue). The echogenicity of these layers depends on their components. The main element of the epidermis is keratin, which account for the intense hyperechogenicity of this layer. Dermis is mostly made of collagen, which is responsible for the moderate hyperechogenicity. The hypodermis is mainly composed of fatty tissue, which accounts for its hypoechogenicity (Fig. 5).[9]

The epidermis, originating from the ectoderm, has a highly pleomorphic cellular content, although 95% of cells are keratinocytes synthesizing keratin.[23,36,37] It appears as a very thin hyperechoic line, continuous and uniform, placed below the anechoic gel. It should not be confused with the probe surface or echo entrance, also hyperechoic. In infants, in eyelid, and in the ventral areas the epidermis is quite thin. Oppositely, in the glabrous skin of the palms and soles, the epidermis is particularly thick and appears as a bilaminar echoic structure, which is the result of the contrast between the epidermis itself and the thick and compact stratum corneum (Fig. 6).[9,23] Color-Doppler will not show any signal, because the epidermis is a nonvascular tissue. The dermal-epidermal junction cannot be distinguished at US.

The dermis has a mesodermal origin and is dominated by packages of organized collagen, providing the supporting structure

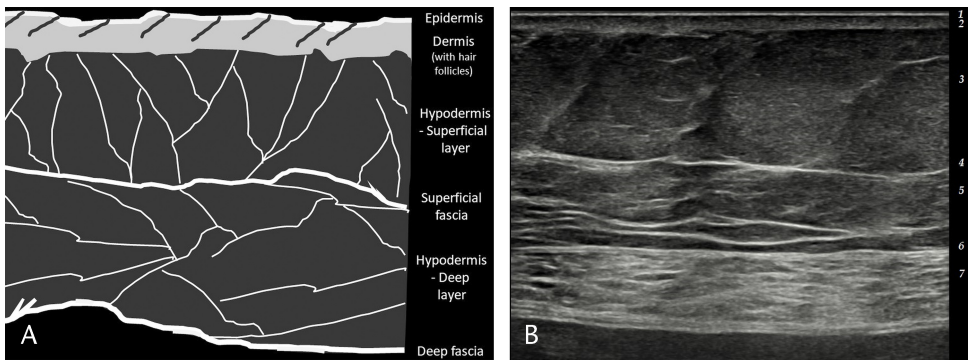

FIGURE 5. Anatomic layers of the skin. A, Schematic drawing. B, Transverse ultrasound scan taken at level of the abdominal wall. From top to bottom the US images shows the epidermis, dermis, superficial fat layer, superficial fascia, deep fat layer, deep fascia, and rectum muscle.

to the skin.[37] It includes blood vessels, lymphatics, nerves, hair follicles, and sweat glands.[23,36] The thickness of the dermis changes in the different body areas and decreases with aging.[18,38] The dermis is thinner in the ventral forearm and thicker (>3 mm) in the dorsal region.[7,8] The dermal echogenicity can also be influenced by the hydration status and the anatomical site. From the histological point of view, the dermis includes the thinner, superficial layer of the papillary dermis and the thicker, deeper layer of the reticular dermis. These 2 layers differ in the way collagen fibers are arranged.[23] US cannot readily differentiate these 2 components, although the upper dermis may be less echoic than the lower one. In the older ages the deposit of glycosaminoglycans produces a hypoechoic upper dermal band on exposed to sun regions, called the subepidermal low echogenicity band.[39] Assessment of this band can be relevant in skin aging studies and aesthetics.[9,23] Importantly, it should not be confused with inflammatory conditions (Fig. 7).

Skin thickness assessment is of special interest in the field of skin aging studies and for aesthetic purposes. A recent systematic US study investigated skin thickness at 20 different predesignated face and neck anatomic sites.[40] The combined epidermal and dermal thickness was approximately 1 mm at the zygomatic process, suborbital area, inferior malar region, gonion, supraglenoid area, and nasolabial-buccal, and nasolabial fold regions. Subcutaneous fat depth was measured to be 2 mm at the forehead; 5 mm at the mental eminence, and 6 mm at the submental, supraglenoid, and temporal regions.

Although present in the dermis, particularly in its deeper portion, vessels are usually not detectable at the common Doppler frequencies used for studying dermatologic lesions, due to their very slow velocity, commonly 2 cm/s or less.[8] Using newer technologies for the study of the microvasculature may allow to detect some more flow signals in the dermis.

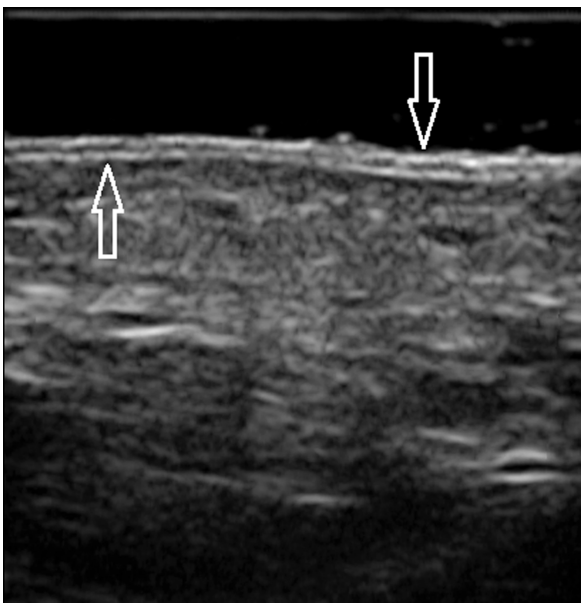

FIGURE 6. Epidermis anatomy. Scan taken at level of the hand palm. The epidermis appears as a double-layered hyperechoic line (arrows).

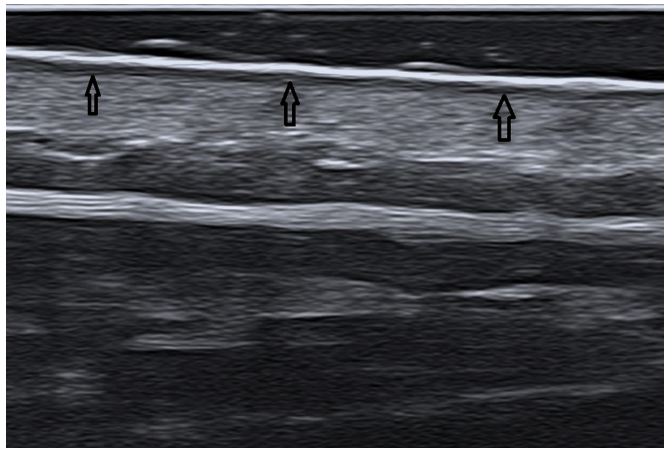

FIGURE 7. Dermis anatomy. The scan taken at level of the forearm dorsal aspect allows recognizing the subepidermal hypoechoic band (arrows).

The hair follicles can be detected in the dermis as small and ill-defined hypoechoic structures arranged obliquely. At 70 MHz, it is possible to detect the sebaceous glands besides the hair follicles (pilosebaceous unit) and the erector pili muscle.[6,17] The bottom of the hair follicles can be found in the dermis as well as the hypodermis, depending on the phase of the hair growth cycle and the anatomic location.[9,23] At 70 MHz, the hair tract within the hair follicle, the apocrine and Montgomery glands can also be observed in some body regions (Fig. 8).[17]

The subcutaneous tissue is the thickest layer. It is thinner in the dorsal aspect of the fingers and more abundant in the trunk.[37] The subcutis is formed of fat lobules, hypoechoic, encased between hyperechoic fibrovascular septa (retinacula cutis) in a honeycomb-like structure. Arrangement, shape, and size of the adipose lobules vary according to the sex, body area, and depth of location.[41] The septa anchor the dermis to the deeper planes. The subcutis anatomy has been investigated in

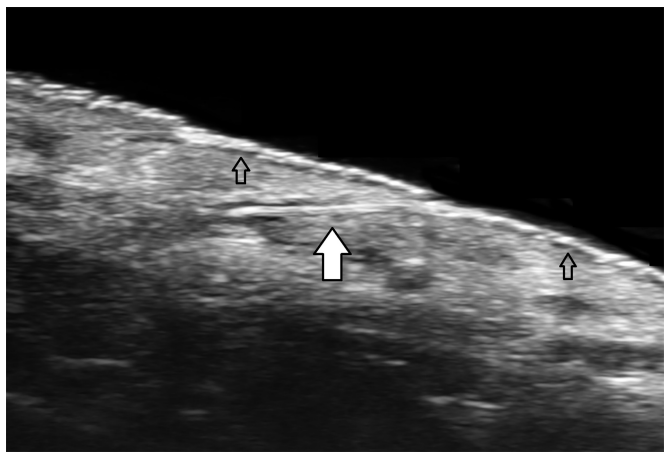

FIGURE 8. Very high-resolution image of the hair follicle. At 70 MHz, the hyperechoic hair shaft is optimally seen crossing obliquely the dermis, inside the hypoechoic hair follicle (white arrow). Also note the subepidermal hypoechoic band (small black arrows) below the epidermis.

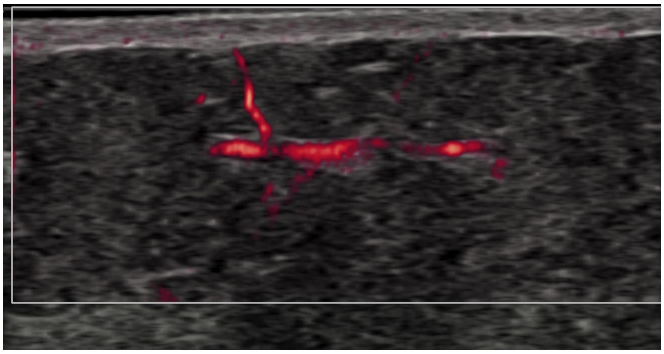

FIGURE 9. Hypodermis vascularization. Power-Doppler scan. Vessel branches are typically seen pointing to the surface and stopping at the dermis-hypodermis edge.

detail at level of the abdominal wall.[42,43] It comprises 2 adipose layers, superficial and deep, with an interposed membranous fascia. The superficial adipose layer is formed of large fat lobules and thin fibrous septa, predominantly arranged obliquely-vertically.[42] It is the one responsible for cellulitis.[41] The membranous layer (superficial fascia) is a continuous fibrous membrane rich in elastic fibers with a nonuniform thickness.[42] In the deep adipose layer, the fibrous septa are less consistent and mostly oriented obliquely-horizontally, whereas the fat lobules are smaller, flat, and less well defined.[42] Below this fat layer there is the deep fascia (muscle fascia) and the muscular plane. The deep fascia has a mean thickness of 1 mm in cadavers and is formed by 2 to 3 layers of parallel collagen fiber bundles.[44] Ligaments between the skin and muscle fascia are extensively present in the face, hands, feet, and breast.[45] At US, fasciae are seen as hyperechoic, continuous, regular lines.[19]

Measurement of the subcutaneous tissue is particularly relevant in the field of obesity, where the thickness of the fat, as measurement in the abdominal wall, correlates with a number of cardiovascular and dysmetabolic issue. A semiautomatic software has been developed to objectively measure subcutis thickness at US.[46] Differently from the dermis, the hypodermis frequently shows vessels at B-mode and color Doppler imaging. Typically, thin, low-speed arteries and, most commonly, larger veins are found within the subcutis, particularly in the superficial portion.[8,16,41] These vessels show branches that stop at the dermal edge (Fig. 9). Sensory nerves may be seen adjacent to the deeper veins in the hypodermis. Lymphatics are not visible.

In the scalp, below the subcutis there will be a thin hypoechoic band corresponding to the galea layer (epicraneous muscle and its aponeurosis) and then a hyperechoic band with dorsal shadowing that marks the bony edge of the calvarium.[6,23] In the face and neck a special value is given to the superficial muscular aponeurotic system (SMAS). The SMAS goes from platysma to the galea aponeurotica, continuing with the temporoparietal fascia.[47–49] From the surface to the depth SMAS the superficial fascia, the muscular and vasculoneuroconnective region, and the deep zone where the connective fascia extends from the deep muscle district to the bony periostium. In the scalp arteries and veins are detected in the hypodermis and running through the galea (the aponeurosis and muscle layer) close to the bony margin.[7]

The stiffness of the skin at elastography varies according to the cutaneous layer being studied. The dermis is more rigid than the subcutaneous tissue. In the subcutis, the septa are more rigid than the fat lobules. Blood vessels are not very rigid in comparison to the surrounding subcutaneous tissue.[31] Using shear-wave elastography in volunteers, Yang et al[50] found that normal skin elastic modulus values are affected by the skin site, sex, and age, with the descending order being the finger, chest wall, forearm, and abdominal wall. The mean elastic modulus values in that study were 30.3, 14.8, 17.8, and 9.5 kPa for the finger, forearm, chest wall, and abdominal wall, respectively. In addition, skin elasticity was higher in men than in women at each site and was more elevated in participants aged 20 to 50 years than in the other age groups at the finger. Body mass index and skin thickness did not influence significantly the values obtained.

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