

REVIEW

Ultrasound in dermatology: Principles and applications

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Ultrasonic imaging has been used in the field of dermatology for nearly 30 years. In this review, we seek to explain the basic principles of ultrasound as they relate to the skin. Based on differences in keratin, collagen, and water content, ultrasonic waves are reflected back to a transducer and translated into a gray-scale image for interpretation. The technicalities of the process and its variations (power, continuous wave Doppler ultrasound, ultrasound elastography) are briefly reviewed, and we further highlight many of the applications for ultrasound in the treatment and diagnosis of dermatologic conditions, including melanoma and nonmelanoma skin cancer, benign tumors, inflammatory diseases, and lipoablation. Each of these entities is uniquely characterized using ultrasonic techniques. Based on published sources, we contend that although ultrasound is still being fine-tuned for application in dermatology and largely remains in experimental phases, it has potential for use in many arenas of our specialty. (J Am Acad Dermatol 10.1016/j.jaad.2011.12.016.)

Key words: benign tumors; cosmetics; imaging; inflammatory disorders; liporeduction; skin cancer; ultrasound.

Ultrasonic imaging was first proposed as an addition to the dermatologic toolbox in the late 1970s, when it was used to measure skin thickness.¹ Since then, the role of ultrasound in dermatology has expanded. Whether searching for the presence of foreign bodies in a soft-tissue traumatic wound, evaluating the inflammatory response to a patch test, or estimating tumor volume in nonmelanoma skin cancer (NMSC), techniques in ultrasound are currently being refined to provide an extra clinical hand, especially as an adjunct to surgical exploration. This review seeks to: (1) describe, in simple terms, the underlying principles of the low-frequency, high-frequency, Doppler ultrasound devices, and ultrasound elastography; and (2) highlight the current applications for ultrasound in dermatology, both diagnostic and therapeutic.

PRINCIPLES

Ultrasonic imaging relies on the properties of reflected sound waves through tissue. Different tissues reflect these waves distinctively, based on intrinsic variations in tissue structure, notably

Abbreviations used:

BCC:	basal cell carcinoma
HFUS:	high-frequency ultrasound
MM:	malignant melanoma
NMSC:	nonmelanoma skin cancer
UAL:	ultrasound-assisted liposuction

vascularity and density, which reflect differences in keratin, collagen, and water content. These variations make ultrasound an important tool in assessing borders and interfaces between regions, eg, between the hypoechoic subcutis and the echogenic dermis, and between a hypoechoic neoplasm and a hyperechoic stroma. Ultrasound measurement entails the transformation of sound waves into visual images; and B-mode scanning, the method of choice in dermatology, translates the reflected waves into “brightness” values on a gray scale, which are then viewed on a monitor (Fig 1).

Low-frequency and high-frequency ultrasound (HFUS) are used for different purposes. Low-frequency ultrasound is used to visualize larger,

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deeper structures, such as internal organs. The superficial anatomy of skin structures and neoplasms are not visible using low-frequency ultrasound. The higher the frequency of the sound waves emitted by the transducer, the clearer the picture, or resolution, of tissues closer to the transducer. The essential point is that there is a trade-off between the clarity of visualization of proximal tissue and the depth of tissue penetration by the sound wave. HFUS, sacrificing deeper spatial discrimination for more detailed superficial pictures, has become the mainstay of ultrasonic application in dermatology in the last two decades.

Practically speaking, 20- to 25-MHz ultrasound will allow the operator to see both the epidermis and the dermis; 50- to 100-MHz ultrasound only provides visualization of the epidermis. The upper limit of resolution as a method of diagnosis is fixed.

Although frequencies of 500 MHz have been used on biopsy specimens to provide extraordinarily clear pictures, sound frequency of this order may damage living tissues, causing heat damage or cavitation.² (In fact, biological engineers investigate principles of cavitation for transdermal drug delivery systems and plastic surgeons have used frequencies in the order of 200 MHz to intentionally cause cavitation in liposuction procedures.)^{3,4} Dermatologic ultrasound is generally within the range of 13.5 to 100 MHz and most high-resolution ultrasound is performed at 20 MHz.⁵ Examination of subcutaneous tumors and regional lymph nodes uses lower resolution ultrasound in the range of 5 to 12 MHz, allowing greater penetration of the sound waves to image these deeper structures⁶ (Table D).⁷

Conventional ultrasound techniques image tissues with stationary interfaces. Conversely, Doppler ultrasound monitors tissues in motion, ie, blood flow. Doppler ultrasound is based on the principle that the transducer and the reflector of the sound wave are moving with respect to each other. Doppler tools calibrate changes in frequency related to the proximity of the moving source. Like conventional stationary ultrasound, Doppler ultrasound has several subtypes, including pulsed wave Doppler, continuous wave Doppler, and duplex ultrasonography.⁸ Pulsed wave Doppler enables the operator to determine the depth of the moving object based on

the latency period between transduction and reception. Continuous wave Doppler, on the other hand, continuously monitors the presence of the moving object without gathering information concerning the depth. Duplex ultrasonography is a conglomeration of B-wave imaging and pulsed wave Doppler, creating a picture of flow. This may be color coded

(color Doppler) to assess directionality of flow, or amplitude coded (power Doppler) to demonstrate the volume of blood flow.⁸

Lastly, ultrasound elastography is a technique used to create an image of the strain on a tissue imposed by a force. It can be used to calculate the degree of elasticity of the tissue being studied. Elastography calls for the comparison of echoes pre-compression and post-compression of a given tissue area. Elastography is currently being considered as an adjunctive mode of non-

invasive imaging in the evaluation of prostate, breast, thyroid, and liver masses, as well as general lymphadenopathy (all organs that are accessible, on which pressure might be exerted by a transducer).⁹ There are still some difficulties with the technique that must be ironed out to create a clinically useful protocol. For example, a desmoplastic response to a breast tumor may create an elastographic image that overestimates the tumor burden because both the tumor and the stromal reaction are registered as relatively hard; one might imagine a similar confounder in the skin.⁹ Nevertheless, elastography is said to have considerable clinical potential in the assessment of lower extremity vascular disease, pressure ulcers, lymphedema, and in the understanding of age-related changes in the skin.⁹⁻¹¹ It has been thought to have implications in the noninvasive characterization of skin tumors as well.¹¹ A recent presentation reviewing data from an elastographic assessment of benign and malignant neoplasms suggested that malignant lesions had significantly lower elasticity than benign lesions.¹²

CAPSULE SUMMARY

- Ultrasound has been used for the diagnosis and evaluation of benign and malignant neoplasms, inflammatory diseases, infectious diseases, and in the forum of cosmetic dermatology.
- Herein, we review the applications for this versatile technology, highlighting the preclinical and new clinical uses that may deserve consideration.
- Ultrasound may benefit the clinician in one of many clinical scenarios, and further studies may be necessary to put this technology to greater use.

APPLICATIONS

Skin cancer

HFUS was first applied to skin cancer diagnosis in the early 1990s. It has been clinically adopted in Europe more than in the United States as a facet of routine skin cancer management and is a required

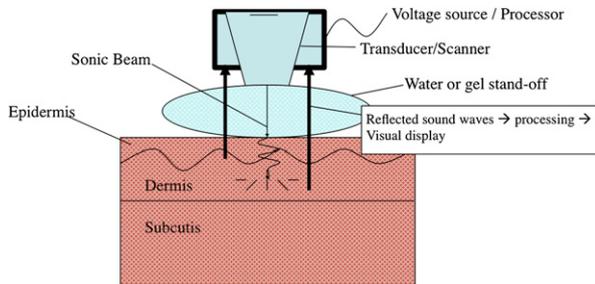


Fig 1. Depiction of ultrasound device, including voltage source, transducer, water or gel stand-off, and sonic beam projected into skin. Sonic beam is reflected back toward transducer from various points in skin, scanned, and processed.

element of dermatologic residency training in Germany.⁸ It is used, variably, in the evaluation and monitoring of both melanoma and NMSC.

As a rule, malignant melanoma (MM), basal cell carcinoma (BCC), and squamous cell carcinoma are each seen as hypoechoic tumors amid hyperechoic surroundings. In addition to clinical considerations, there are ultrasonographic means of distinguishing among the 3 tumors, although none have replaced the need for histopathologic assessment. Some studies have characterized BCC as including multiple hyperechoic (echogenic) spots, as opposed to MM, which remains hypoechoic throughout.^{13,14} Other research has focused on HFUS as a low-cost means of differentiating seborrheic keratoses and benign nevi from melanoma.¹⁵ Harland et al¹⁵ determined that seborrheic keratoses could be differentiated from melanoma ultrasonographically with 100% sensitivity and 79% specificity whereas benign nevi were considerably more difficult to distinguish, accomplishing a 30% specificity with a test sensitivity set at 100%.

More than distinguishing between benign and malignant lesions, however, HFUS has considerable potential to provide the dermatologist with information regarding tumor margins, although many have suggested that further refinement is needed before clinical protocols are established¹⁶⁻¹⁹ (Fig 2). One recent publication correlated the ultrasonographic assessment of superficial and nodular BCCs with the histopathological measurements of the tumors post-excision (with fixed 4-mm margins), determining that HFUS was able to accurately predict which tumors had subclinical extension beyond 4-mm margins in 48 of 50 cases.²⁰ The remaining two tumors were determined to be infiltrative and morpheaform and were not able to be properly outlined using HFUS technology. Another study, examining the role for HFUS in improving the surgical precision of Mohs micrographic surgery for

Table I. Frequency of ultrasound and corresponding tissue visualization

Frequency of ultrasound, MHz	Approximate depth of penetration, cm	Visualization
7.5	>4.0	Subcutis and lymph nodes
13.5-50	3.0-0.3	Epidermis and dermis
20	0.6-0.7	Epidermis and dermis
50-100	0.3-0.015	Epidermis only

NMSC (regardless of histologic subtype), found that HFUS was more sensitive in determining subclinical extension of larger (>1.74 cm²) tumors but was not adequately sensitive in picking up more subtle areas of extension in smaller and more insidious tumors.¹⁹ Similarly, other work to evaluate the role for ultrasound in examining the boundaries before Mohs micrographic surgery determined that 20-MHz ultrasound was not superior in estimating tumor size to clinical assessment alone.²¹ It may be that HFUS is more suitable for application in larger excisions than in Mohs micrographic surgery at the present time. Supporting the notion that HFUS may be more sensitive in detecting larger tumors, other researchers, investigating the role of HFUS (20 MHz) in the preoperative staging of melanoma, found that HFUS measurements correlated well with depth in larger melanomas (>0.76 cm) but were not sufficiently accurate in thinner melanomas.²² There is new evidence that using HFUS at an even higher frequency, with lower penetrance, may be more successful in estimating tumor size than HFUS at 20 MHz. A team of investigators found that using HFUS at 75 MHz rather than 20 MHz did, in fact, correlate significantly with Breslow depth in lesions that were an average of 0.4-mm thick. They suggest that this mode of preoperative scanning, with its higher frequency, might in fact provide a reliable means of predicting lesion size.²³

There are other limitations to the use of HFUS to establish tumor margins. Inflammatory infiltrates associated with BCC and MM may create hypoechoic extension leading to an overestimation of tumor size. Furthermore, reticular dermal extension of BCC may not be visualized with the 20-MHz HFUS, requiring frequencies on the order of 13 to 15 MHz.²⁴ If a tumor extends into the subcutis, delineation may be difficult given that the subcutis is hypoechoic as well, and thus HFUS may not be suitable for the evaluation of deeper tumors.²⁴ Finally, hyperkeratotic squamous cell carcinomas may not be well visualized on HFUS.²⁴

Lower resolution (7.5-10 MHz) ultrasound can be applied to aid the dermatologic surgeon in the



Fig 2. Two-dimensional sonogram of basal cell carcinoma in melomental crease. Penetration 1.1 mm, tumor width 4 mm.

estimation of subcutaneous tumor bulk and in assessing the proximity of a tumor to vessels and nerves.²⁴ Ultrasound at 7.5 to 10 MHz may also be important in the evaluation of lymphatic spread and lymph node involvement of skin cancer, and some studies have asserted that ultrasound is more sensitive and specific in detecting lymphatic spread of melanoma than physical examination alone, detecting 25% to 30% more patients with regional lymph node metastases.^{25,26} Ultrasound evaluation of regional lymph nodes is recommended in Germany and France for the routine follow-up in patients with melanoma greater than 1 mm in depth.²⁷ Vassallo et al²⁸ and Solbiati et al²⁹ organized criteria for recognizing the ultrasonographic characteristics of lymph node metastases, differentiating metastatic spread from reactive lymphadenopathy. These studies characterized lymph nodes with metastases as round, with generally sharp borders, and hypoechoic or echolucent centers—the result of liquefaction necrosis.^{24,28,30} Reactive lymphadenopathy, on the other hand, is represented by enlarged elliptical lymph nodes with a vascular and hyperechoic center.²⁸ A recent study examined high-resolution ultrasound for use in preoperative identification and characterization of sentinel lymph nodes in 25 consecutive patients with cutaneous melanoma.³¹ B-mode HFUS correctly identified two of 6 positive lymph nodes, with sensitivity of 33.3%, specificity of 100%, positive predictive value of 100%, and negative predictive value of 87.9%. The authors concluded that HFUS cannot replace sentinel lymph node biopsy especially in detection of micrometastasis, however it may be a useful modality in assessing the lymph node status for macrometastasis presurgically.

Doppler ultrasound, or its extension, duplex sonography, is a logical addition to B-scanning

ultrasound to allow visualization of the hilar blood flow of lymph nodes. Moehrle et al³² reported that reactive lymphadenopathy typically demonstrates hilar vessels on color Doppler sonography, whereas metastatic lymphadenopathy generally does not. Other studies have demonstrated that metastatic lymphadenopathy may show an asymmetric vascular pattern and marginal flow whereas reactive lymphadenopathy tends to demonstrate a more central pattern of vascular flow.³³ Contrast enhancement of color Doppler scanning may provide additional help in the evaluation of reactive versus metastatic lymphadenopathy as well.³⁴ Some have argued that the amplitude of flow (power Doppler), as calculated by resistance and pulsatility on color Doppler ultrasound, is not a highly reliable criterion in the confirmation of metastatic disease.^{32,35}

Conversely, some specialists believe that Doppler ultrasound techniques to evaluate the vascularity of a tumor may shed valuable light on the aggression of the tumor. Work has been done to imply that verrucae with a high vessel density may grow faster and deeper, exhibiting a greater resistance to treatment.³⁶ Similarly, studies have suggested that relatively avascular melanomas may grow more slowly whereas those that are hypervascular may have greater metastatic potential.³⁷ This may be immediately useful after thermal treatments where the imaged blood flow vanishes, and a persistent vascular focus may suggest that retreatment of the area is needed.³⁸

Although routine imaging examination after clinically curative surgery for melanoma is not yet recommended by the American Academy of Dermatology, HFUS, as a relatively inexpensive and easily performed examination, may have value together with the physical examination for the

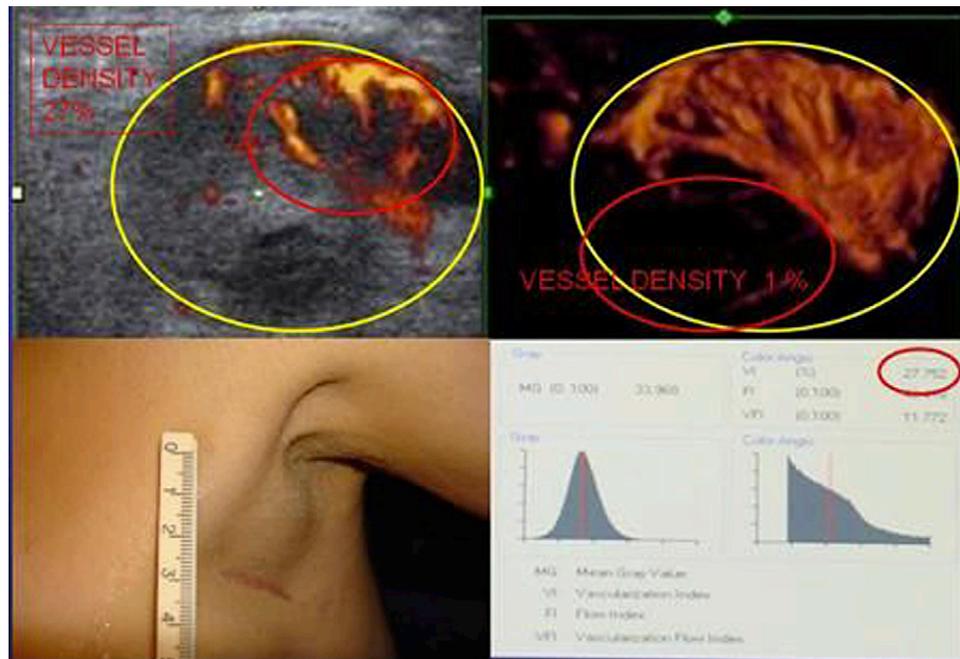


Fig 3. Three-dimensional Doppler sonogram with vascular index histogram. Metastatic melanoma to axillae. Recurrent nodal 12-cm³ volume of tumor shows 8 cm³ of necrotic tissue with vascular index of 1% and 4 cm³ of hypervascular cancer with vascular index of 27%. Follow-up studies may be used to compare changes in vessel density posttherapy.

monitoring of patients with intermediate-risk cutaneous melanoma, especially as this technology is increasingly refined.³⁹⁻⁴¹ Solivetti et al⁴² assert that HFUS may be useful in detecting satellite and in-transit metastases spreading through the lymphatics between the primary melanoma (>1 mm) and the lymph node basin draining the area. They report that ultrasound was able to detect clinically unrecognizable lymph node metastases in 63 of 600 patients followed up. The authors used a series of probes from 7.5 to 20 MHz to ensure visualization of lesions that may be well imaged at one frequency but invisible at another. In addition, they suggest that fine needle aspiration under HFUS guidance may be used to confirm imaging findings. Hengge et al⁴³ investigated the economic implications of this means of surveillance, suggesting that for all stages of melanoma, physical examination and lymph node ultrasound were the most cost-effective means of surveillance at an estimated \$186.77 per lymph node ultrasound examination. With further work, the data imply that there may be a screening role for the use of this modality to assess and target locoregional disease (Fig 3).

In sum, HFUS is currently being used for MM and lymph node surveillance in Europe. Less commonly it is used in the preoperative evaluation of NMSC. It may be useful in imaging larger tumors before surgical intervention.

Inflammatory diseases/infectious diseases/benign neoplasms

Ultrasonic imaging with frequencies up to 50 MHz have also been used for the characterization of inflammatory diseases, including scleroderma, localized morphea, lichen sclerosis et atrophicus, spongiotic dermatitides, and hidradenitis suppurativa. As early as 1981, ultrasound was used to measure the increase in skin thickness in scleredema.⁴⁴ A recent investigation applied ultrasound to the discrimination of lichen sclerosis et atrophicus from morphea,⁴⁵ and another calibrated the response to treatment with the patterning of dermal collagen in localized scleroderma using high-resolution ultrasound with histopathological correlation.⁴⁶ Still others have used ultrasound to determine the extent of subclinical cystic lesions in hidradenitis suppurativa before surgical excision.⁴⁷ The same authors also used ultrasound to evaluate for the presence of lymphadenopathy in hidradenitis suppurativa, determining that this was likely the result of superinfection in advanced disease.⁴⁸ El-Zawahry et al⁴⁹ conducted a substantial review of ultrasonic characteristics of 8 common skin disorders (morphea, keloids, lichen planus, chronic eczema, psoriasis, port-wine stains, seborrheic keratoses, and photoaged skin), using ultrasound at 50 MHz to measure mean epidermal and dermal thickness in 57 patients, and detailing the echogenic characteristics of each lesion examined.

Although this kind of examination is not commonly performed, as US dermatologists are not regularly trained to assess inflammatory diseases with ultrasound, and patients may undergo simple biopsy procedures, perhaps it might be an option for those patients reluctant to undergo repeated biopsies for intransigent dermatoses and a helpful blueprint for surgical planning.

Doppler ultrasound has shown great promise in evaluation of scleroderma. It has been used to diagnose scleroderma by analyzing structural changes in tissue and vascularity. Some believe that Doppler ultrasound may further prove useful in monitoring disease activity.⁵⁰ Hesselstrand et al⁵¹ used 20-MHz ultrasound to evaluate patients with systemic sclerosis of less than 2 years' duration. They demonstrated that HFUS was more sensitive than clinical assessment alone in detecting the edematous phase that occurs before fibrotic stage. The authors concluded that HFUS may allow for the identification of patients with diffuse skin involvement very early in the disease process, and in assessing the severity of the skin disease.⁵¹ Ultrasound has also been used to interpret treatment outcome in inflammatory dermatoses. In skin disorders such as morphea and sclerosis, response to treatment is commonly assessed using a scoring system based on palpation. Because such a scoring system is inherently subjective, Bendeck and Jacobe⁵² used ultrasound to illustrate the criteria for an outcome measure that are quantitative, valid, and reproducible. Because tissue characteristics such as thickness, vascularity, and echogenicity vary by individual, examination of the contralateral side or an uninvolved "control" site is important in accurate assessment with ultrasound. Sensitivity, accuracy, and validity of ultrasound for these disorders of skin thickening has yet to be established.

Infectious diseases of the skin may also have a place for ultrasonographic assessment. A review conducted by Blankenship and Baker⁵³ assessed various imaging modalities in the detection of retained foreign bodies in traumatic soft-tissue wounds, which, if left undetected, may lead to infectious and allergic consequences as well as serious long-term disability. They suggested that, based on previous clinical data, detection of relatively superficial foreign bodies, especially those that are radiolucent and difficult to pick up with other means of imaging, may be enhanced significantly with ultrasound examination using a 7.5-MHz frequency in the emergency department.⁵³ Ultrasound has also been used in the detection of abscesses with improved sensitivity when compared with physical examination alone.⁵⁴ Previous research has

suggested that drainage of breast abscesses with ultrasound guidance leads to an less invasive procedure with improved cosmesis when compared with surgical incision.^{55,56} Although not routinely used in the evaluation of cellulitis, ultrasound may be used for diagnosis at an earlier stage by detecting edema in the subcutaneous tissue, reflected as a diffuse increase in the echogenicity.

Cabrera et al⁵⁷ reported cases of necrotizing gangrene of the genitalia and perineum and suggested that ultrasound may prove beneficial in assessing for the presence of gas or testicular involvement on initial presentation. Two recent reports used ultrasound to quickly diagnose necrotizing fasciitis of the upper extremity, noting subcutaneous emphysema and deep fascial thickening secondary to fluid collections and gas in the deep fascial plane.^{58,59} Other clinicians have applied ultrasound for therapeutic purposes, using 25-kHz acoustic waves to rapidly and successfully achieve debridement of chronic wounds.⁶⁰

Ultrasonic imaging is also being investigated for use in diagnosis of subcutaneous benign lesions. Ulrich and Gollnick⁶¹ analyzed more than 800 sonograms of lymph nodes, melanoma metastases, lymphosarcomas, hemangiomas, lipomas, cysts, and trichoepitheliomas using 7.5-MHz ultrasound. They pointed out that MM metastases were nearly anechoic, whereas benign subcutaneous tumors were rather echogenic. The echo pattern of lipomas was very similar to that of subcutaneous fat tissue, although the echogenicity was often greater because of the additional morphologic features present in lipomas (fibrolipomas, angioliipomas). Trichoepitheliomas were also homogeneous echogenic tumors. The sonographic pattern of hemangiomas varied depending on patient's age, changes in vascularization, and the degree of remission with thrombosis. (In an earlier study, Dubois et al⁶² pointed out that ultrasound evidence of high vessel density and Doppler shifts are also suggestive of hemangiomas rather than other soft-tissue neoplasms.) Simple cysts were almost completely anechoic, whereas complex cysts exhibited a varying degree of echogenicity depending on their content.⁶¹ In further characterization of superficial soft-tissue lipomas using high-resolution sonography, Fornage and Tassin⁶³ described lipomas as elongated, isoechoic or echogenic masses within subcutaneous tissue (Fig 4). Takemura et al⁶⁴ found ultrasonographic imaging helpful in assessing the condition of the epidermal cyst wall, aiding the surgeon in determining the best method of excision. In a retrospective study of 183 patients with lipomas, epidermal cysts, and ganglions, Kuwano et al⁶⁵

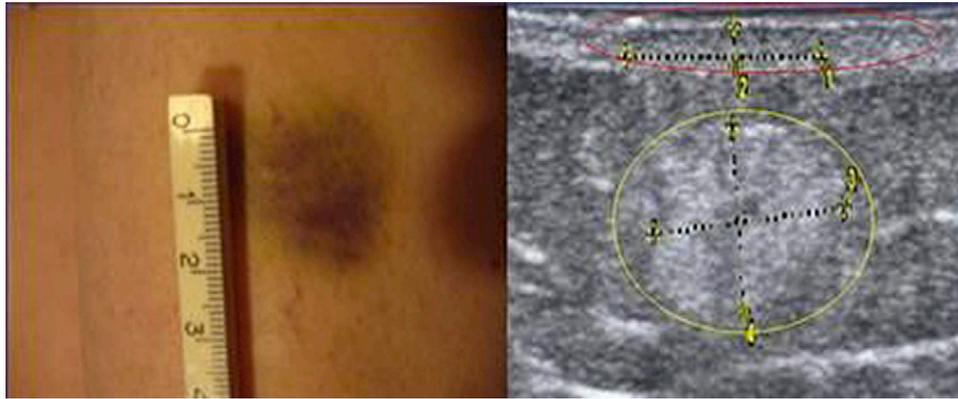


Fig 4. Two-dimensional sonogram (*right*) of ecchymosis (*left*). Ecchymosis produced echo-poor changes in dermis. Patient had underlying hyperechoic 2-cm subcutaneous lipoma.

found that ultrasound significantly increased the specificity of preoperative diagnosis when compared with palpation alone. Indeed, the authors suggest that small subcutaneous lipomas that are clinically palpable and of concern to the patient are often missed by standard magnetic resonance imaging protocols and may be readily imaged with HFUS. Taking one step further, Futani et al⁶⁶ used power Doppler to understand the differing characteristics of histologically proven well-differentiated liposarcomas versus benign intramuscular lipomas. They point out that although all of the 3 liposarcomas were noted to have 2-velocity vascular signals, only one of the 9 lipomas was noted to have a 2-velocity signal. They point out that ultrasound is a potential means of discriminating between the two entities.

Cosmetics

The cosmetic arena has also used ultrasound for both diagnostic and therapeutic purposes. Therapeutically, ultrasound has been especially relevant to the field of liporeduction. The technique of ultrasound-assisted liposuction (UAL) was first developed by Michele Zocchi in the late 1970s and was initially used in Europe and South America.⁴ It was introduced in the United States in 1997.⁴ Applying a probe with 20- to 27-kHz frequencies to selectively destroy adipose tissue, UAL promised to allow surgeons an easier hand in approaching fibrous areas, especially in secondary liposuction procedures, and a more rapid evacuation of fat. The UAL technique offered the benefit of targeting adipocytes while sparing nerves and smaller blood vessels, and superficial UAL was said to cause superior collagen contraction and skin tightening.⁴ Initial investigations, however, showed that UAL conferred a higher risk of tissue burns and seromas, and some thought that the UAL cannulas were unwieldy. Because of these drawbacks, the American Society for

Dermatologic Surgery does not recommend the procedure.⁶⁷ UAL is currently being further refined. Recent retrospective analyses have suggested that the safety and efficacy of UAL is improving significantly.⁶⁸

Ultrasound has also been applied to liporeduction in a noninvasive manner. Ultrasound devices have emerged in the field of body contouring as a means of ablating adipocytes. This technology allows for the delivery of a small amount of ultrasonic energy (low energy density) in the epidermis and dermis and an additive amount in the subcutis, disrupting adipocytes and promoting fat resorption.⁶⁹ Even more recently, an ultrasonic device has emerged as a means of nonablative rejuvenation of the face and neck, receiving Food and Drug Administration approval in 2009 (Ulthera System, Ulthera Inc, Mesa, AZ). In its first clinical study to evaluate the safety and efficacy of treatment, Alam et al⁷⁰ used 4- and 7-MHz probes to deliver energy to depths of 4.5 or 3.0 mm with pulse durations of 25 to 40 milliseconds, creating zones of coagulation necrosis in the dermis and subcutis, and promoting visible skin tightening. Blinded observers were able to assess results 90 days after treatment and an analysis revealed that 86% of subjects achieved a clinically apparent brow lift from the procedure.⁷⁰ In a cadaveric study, Laubach et al⁷¹ established that this prototype creates a cone-shaped zone of necrosis in the reticular dermis without affecting the overlying epidermis, obviating the need for concurrent tissue cooling.

Finally, consistent with its initial use, ultrasound has been used as a means of evaluating liporeduction postmesotherapy. Recent studies evaluated the response to a cryolysis device for subcutaneous contouring using 7.5-MHz frequencies.^{72,73}

Diagnostic ultrasound has been applied to quantify facial aging. In 1989, authors identified a characteristic low echogenic band just below the epidermis

in sun-damaged skin—called a “subepidermal low echogenicity band.”⁷⁴ Further studies have used ultrasound to show increased echogenicity with the use of dermal hyaluronic acid implants.⁷⁵ Therapeutically, ultrasound (5 MHz) has been used as a method for improving penetration of cosmetic topicals in the process of phonophoresis.⁷⁶ Topicals used in conjunction with ultrasound have included ascorbyl glucoside and niacinamide to enhance skin lightening.

Conclusion

The techniques of ultrasound are well understood, and there are many applications for ultrasound in the field of dermatology. Some of these applications are currently under investigation, and studies are underway to refine ultrasound technology and equipment for both diagnostic and therapeutic purposes. It is important to note that ultrasonic diagnosis requires significant operator skill and training, and there is a learning curve to ultrasonic interpretation. Nonetheless, with the generation of more interest in such applications, ultrasound has the potential to become an increasingly useful modality in general and surgical dermatology.

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