Program Digest, 2019 IEEE International Ultrasonics Symposium (IUS)
Glasgow, Scotland, October 6-9, 2019

Handheld High-Resolution Ultrasonic Scanner for Quantitative Assessment of Skin Conditions

Fedar Seviaryn
Institute for Diagnostic Imaging Research
University of Windsor
Windsor, Canada
seviary@uwindsor.ca

Eugene Malyarenko
Sonamed Technologies LLC
Birmingham, MI, USA
em@tessonics.com

Gregory Schreiner
Institute for Diagnostic Imaging Research
University of Windsor
Windsor, Canada
schreing@uwindsor.ca

Ina Seviaryna
Institute for Diagnostic Imaging Research
University of Windsor
Windsor, Canada
seviary@uwindsor.ca

Roman Gr. Maev
Institute for Diagnostic Imaging Research
University of Windsor
Windsor, Canada
maev@uwindsor.ca

***Abstract*—High-frequency ultrasound is a relatively new diagnostic technique that has shown potential to be a useful tool in different aspects of dermatology. This work presents an application of acoustic microscopy to non-invasive imaging of human skin, to identify fine skin structures and characterize skin lesions. Our research group has developed a portable ultrasonic microscope operating at 50 MHz and providing B-scans with 12 mm length and up to 3 mm depth, with axial resolution of 14 µm and lateral resolution of 70 µm. The design of this handheld skin scanner allows comfortable and convenient operation in a clinical environment. Raw acoustic data are processed to reduce noise, optimize the dynamic range and to form a two-dimensional B-scan image. The system non-invasively visualizes the outermost structures of the human skin, focusing on the upper dermis. The skin on different parts of the human body was imaged in healthy volunteers. Both the primary skin layers and skin appendages are identified in the obtained acoustical images. The benign melanocytic lesions and skin scars have been characterized by their acoustic properties. Skin layer thickness measurements at different parts of the body provide a base for statistical analysis and give information about skin conditions. Evaluation of skin morphology based on elastic modality has a significant potential for characterizing and monitoring skin condition. The skin images and their automated analyzer can be useful in dermatology for surgery planning and image-guided intervention, assessment of wound healing and skin grafts. The ultrasonic morphology analysis also has an excellent perspective for research and regular monitoring in the cosmetic industry.**

Keywords*—*high-frequency ultrasound, skin imaging, signal processing.

I. Introduction

Ultrasonic imaging has become a routine medical modality in dermatology [1]–[3]. The method does not require the administration of contrast agents. The limits of conventional ultrasound to detect very thin lesions (<100 microns) and lesions in the epidermis have been pushed from about 20 to over 50 MHz and beyond in last decades enabling new applications for the ultrasound. A sharp trend in utilizing high-frequency ultrasound skin imaging for diagnosis and treatment has been observed.

The skin is the largest organ in the body; it produces a significant variety of tumors, both benign and malignant. This creates challenges for screening, diagnosis and treatment. With biopsy as the gold standard for diagnostics analysis of such lesions, there is a need for non-invasive, cost-efficient and fast technique assisting diagnosis and efficient treatment or removal of the lesion. Providing real-time high-resolution images, ultrasound presents detailed anatomically correct data of skin pathologies. Interventional procedures such as tumor biopsy, removal of a foreign object, localization of the needle, and surgery planning to determine the neoplasm dimensions can be performed with assistance of high-frequency ultrasound. Ultrasound may also be used to monitor the therapeutic response of skin treatment [4]. Measurements in ultrasound images have a reasonable correlation with pathology [5], [6]. The demand for skin imaging is also arising from people's increased concern with skincare and aesthetic appeal. Most lesions examined in skin ultrasound involve subepidermal structures that can be assessed with high-frequency ultrasound only. Modern high-frequency ultrasound systems use small (~12 mm) probes with full contact with the skin surface to reduce scattering artifacts and allow resolution of 20 microns and up to 3.5 mm penetration depth [7], [8]. In this study, the skin was non-invasively evaluated using a 50 MHz handheld ultrasonic scanner specially designed for high-quality data acquisition at increased penetration depths.

II. Methods

The ultrasonic skin scanner was designed as a small hand-held probe. It is equipped with a 50 MHz focused ultrasonic transducer (focal depth 6mm) moving along the skin surface with a stepper motor. Both the driver and the motion controller reside inside the probe. An external pulser-receiver and a digitizer with a sampling frequency of 400 MS/s are used for the data acquisition. The transducer is excited by a short negative pulse with up to 90 V amplitude and 5 ns duration. The returning echoes are amplified by 20-46 dB digitized and stored in the onboard memory. After scanning, data are transferred via USB3 interface to a computer for signal processing, image enhancement and reporting. The scanner produces B-scans with a width of 12 mm and depth of 3 mm. The axial resolution is 14 µm, and the lateral resolution is 70.0 µm.

The main program on the host computer controls the operation of the probe. It transfers data, provides frequency filtering and processes the digitized signals to reduce noise. A-scans and composed B-scans are displayed in separate windows. The program also provides some standard processing of the B-scans to represent features of the skin structure.

The acoustic data acquired from the device were processed using a custom MATLAB algorithm. Each image is of the absolute value of the Hilbert transform of the signal. The grayscale map was set such that echo level corresponded linearly to grayscale up to a specific cutoff value, beyond which it would respond logarithmically. This standard "pivoting" procedure provides better contrast for low amplitude signals without saturating the high amplitude signals. The algorithm also applies a frequency filter to reduce background noise. To obtain uniform resolution at various depths, two B-scans of the same area were taken with different depths of focus and were aligned and stitched together. Image alignment was performed in MATLAB using a control point-based registration algorithm in the image processing toolbox. The top half of the B-scan with the shallower focus and the bottom half of the B-scan with the deeper focus were then combined to form a single image, achieving considerably more uniform high resolution throughout the entire image than is possible with a single B-scan (Fig. 1).

A brightness windowing filter was employed to improve image contrast for a specific frequency band of reflected intensities at the cost of reducing the contrast for intensities outside of this band. Additional processing of the stored data may be performed with external software.

We obtained images of 20 healthy participants at six different anatomical locations. Besides healthy skin, various skin conditions such as ecchymosis, burns, and scars have been assessed, measured and characterized by their acoustic properties. Standardized measurement procedures were applied to all participants. To measure the thickness of the skin, eight B-scans of a dorsal forearm were taken for each participant. The thickness of the skin was measured in four different locations in each image, totalling to 32 measurements.

III. Results

A. Healthy Skin Imaging

Ultrasound at 50 MHz frequency can clearly define the morphology of skin layers and evaluate epidermal and dermal thickness. High-resolution ultrasound imaging of healthy skin shows a clear differentiation of skin layers (Fig.1). Two main structural components of skin, collagen and keratin, determine

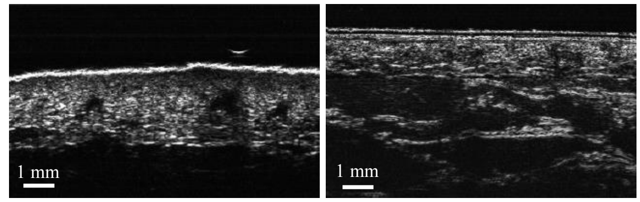

Fig. 1. Ultrasonic image of healthy skin. (a) Single, (b) combined focal depth.

the main echo pattern on ultrasonic images [9]. The upper detectable layer just below the entrance echo represents the epidermis. The thickness of epidermis depends on the anatomical location; it is thicker in the palmar areas (Fig.2). The dermal layer is a hyperechoic band varying in thickness. The echogenicity of the reticular dermis is slightly higher than that of the papillary dermis due to a high concentration of collagen fibres, which are strong reflectors of ultrasound [10]. The collagen fibre network in the reticular dermis is responsible for the strong echogenicity. Subcutaneous tissue seen as a highly hypoechoic layer is partially visible. The brighter hyperechoic lines within the subcutaneous tissue are fibrous septs. Hair follicles (appearing as slanted and slightly curved dark regions) and sweat glands (narrow vertical lines with an opening on the skin surface) are detectable throughout the skin (Fig. 3). Often, only part of the hair follicle is visible on the ultrasonic scan indicating that the remainder of the structure lies out of the plane of the image. Blood vessels appear as thin echo-free ducts (Fig. 2). No significant arteries were detected in the dermis.

B. Benign lesions

Fig. 3 demonstrates acoustic representations of ephelide (freckle), mole and papilloma. The mole is a benign melanocytic nevus caused by an accumulation of melanocyte cells in a small area while the ephelide is an accumulation of melanin in epidermal area. The papilloma is a benign epithelial tumor growing outwards. The nevus and papilloma have well-defined borders making the contours easy to determine; the structure can be seen both above and below the skin surface. The nevus shape and edge can be used as characteristic features in nevus diagnosis.

C. Thermal Burn Healing Process

Non-invasive monitoring of wound depth, scar tissue volume, and healing progress of skin injuries is a potential application for the high-resolution skin scanner in a clinical setting. Ultrasonic images of a minor burn wound were taken one day after it was incurred and then retaken six days later (Fig. 4). The burn was classified by appearance as deep partial (IIb). This type of thermal burn affects the deeper layer of the dermis [3]. The thermal injury can be seen as a dark region

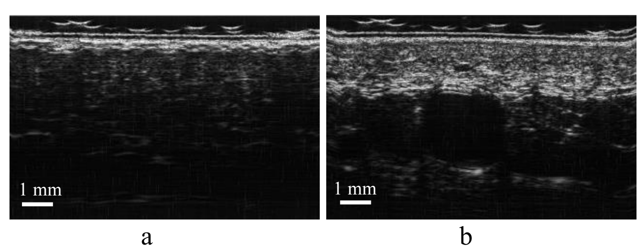

Fig. 2. Ultrasonic images of the palmar area (a), tourniqueted basilic vein (b).

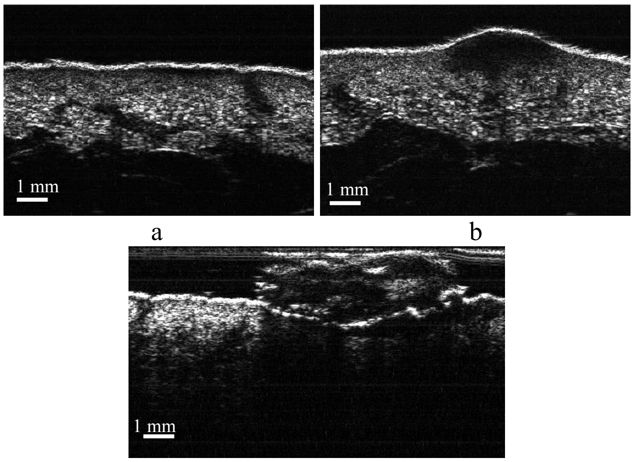

Fig. 3. Ultrasonic images of ephelides (a), benign nevus (b), papilloma (c).

extending from the skin surface to the bottom of the epidermis. The burned area extends through the epidermal region and into the dermis. A full hair follicle can also be seen in Fig. 4a, as well as a sweat gland appearing as a thin, hypoechoic vertical line. In Fig. 4b, the same wound can be seen after given six days to heal. The hypoechoic scar tissue was found to extend deeper into the tissue than the first image of the wound while the lateral dimension of the wound stayed the same. It is known that the depth of the burn would evolve over time, especially for more severe wounds due to developing necrosis and apoptosis [3]. After six days, the inflammatory response should be taken into account. It is known that inflammatory cells have high acoustic attenuation [4], [5]; this process can also contribute to the low echogenicity of the burn. Also, the beginning of the proliferative phase of wound healing with a high number of fibroblasts present to rebuild the tissue may contribute to the increased depth of the wound.

Because of the wound progression over time, periodical evaluation of the burn depth is required to assess the degree of the burn. Review of publications on an ultrasonic assessment of burn wounds shows that low-frequency ultrasound often fails to reveal the burn/dermis interface [4]. A high-frequency handheld imaging system could fill the gap in demand for non-invasive imaging modalities for cutaneous applications. Quantitative analysis of the burn therapy treatment would be useful in planning clinical care and research.

D. Measurements of Skin Thickness

The average skin thickness was found to be 2160 ± 450 μm, which is in good agreement with other published research that found the female dorsal forearm skin thickness to be 2310 ± 954 μm [6]. This indicates that there is little widespread vertical distortion that is significantly affecting vertical measurements in

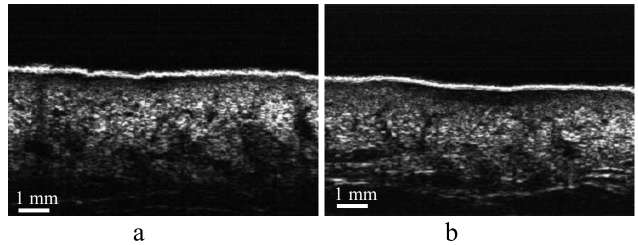

Fig. 4. Thermal burn of the skin. (a) one day, (b) six days after.

the images and gives reassurance that the vertical scales of the images were correctly labelled.

CONCLUSIONS

Human skin structure, especially epidermal and dermal layers, were observed non-invasively by handheld ultrasonic skin imager with the central frequency of 50 MHz. Non-invasive imaging support provided with high-resolution ultrasound can be a powerful diagnostic and monitoring tool in the medical and aesthetic dermatology. The detailed skin anatomical data provided by high-resolution ultrasound may support the diagnosis and management of a wide variety of skin conditions by specialists.

REFERENCES

[1] E. de O. Barcaui, A. C. P. Carvalho, F. P. P. L. Lopes, J. Piñeiro-Maceira, and C. B. Barcaui, "High-frequency ultrasound with color Doppler in dermatology.," An. Bras. Dermatol., vol. 91, no. 3, pp. 262–73, 2016.

[2] A. Polańska, A. Dańczak-Pazdrowska, M. Jałowska, R. Żaba, and Z. Adamski, "Current applications of high-frequency ultrasonography in dermatology," pp. 535–542, 2017.

[3] R. Kleinerman, T. B. Whang, R. L. Bard, and E. S. Marmur, "Ultrasound in dermatology: Principles and applications," J. Am. Acad. Dermatol., vol. 67, no. 3, pp. 478–487, Sep. 2012.

[4] E. Szymańska et al., "Skin imaging with high-frequency ultrasound - Preliminary results," Eur. J. Ultrasound, 2000.

[5] X. Wortsman, "Sonography of the Primary Cutaneous Melanoma: A Review," Radiol. Res. Pract., 2012.

[6] X. Wortsman and G. B. E. Jemec, Dermatologic Ultrasound with Clinical and Histologic Correlations. .

[7] A. N. Khlebnikova, V. A. Molochkov, E. V. Selezneva, L. A. Belova, A. Bezugly, and A. V. Molochkov, "Ultrasonographic features of superficial and nodular basal cell carcinoma," Med. Ultrason., vol. 20, no. 4, p. 475, Dec. 2018.

[8] M. A. Kim, E. J. Kim, and H. K. Lee, "Use of SkinFibrometer ® to measure skin elasticity and its correlation with Cutometer ® and DUB ® Skinscanner," Ski. Res. Technol., vol. 24, no. 3, pp. 466–471, Aug. 2018.

[9] P. A. Chandraratna, P. Whittaker, P. M. Chandraratna, J. Gallet, R. A. Kloner, and A. Hla, "Characterization of collagen by high-frequency ultrasound: evidence for different acoustic properties based on collagen fiber morphologic characteristics.," Am. Heart J., vol. 133, no. 3, pp. 364–368, 1997.

[10] K. P. Mercado, M. Helguera, D. C. Hocking, and D. Dalecki, "Noninvasive Quantitative Imaging of Collagen Microstructure in Three-Dimensional Hydrogels Using High-Frequency Ultrasound," Tissue Eng. Part C Methods, vol. 21, no. 7, pp. 671–682, 2014.