IN VIVO CHARACTERIZATION OF HUMAN FINGERTIP AND FOREARM SKIN USING ATTENUATION OF HIGH FREQUENCY ULTRASOUND

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Abstract - Attenuation of high frequency ultrasound (10-55 MHz) by skin layers and subcutaneous fat was studied in vivo using 16 normal subjects aged 19 to 34. Attenuation values at several frequencies were obtained by computing the slope of spectra vs. depth (dB/mm). Diffraction effects were eliminated using axial translation of the focal zone within the tissue. Data were collected from three sites in the body: fingertip, dorsal side of forearm near the wrist, and dorsal side of forearm near the elbow. At 25 MHz, significant differences in attenuation were found between dermis at the fingertip and the two forearm regions (9.5±2.5 vs. 2.7±2.6 and 1.8±2.1 dB/mm, Mean±SD among the subjects). The corresponding mean attenuation coefficients were 0.32, 0.21 and 0.20 dB/mm/MHz respectively. Significant differences were not found between the dermis and fat at the forearm regions. These results are expected to aid future studies on quantitative characterization of skin tissues using high frequency ultrasound.

I. INTRODUCTION

High frequency ultrasound has several potential applications in dermatology [1]. However conventional B-scan images of skin seem to have limited utility from a clinical perspective. For example, earlier work on high frequency ultrasonic imaging of skin indicates that purely based on conventional B-scan images, it is difficult to differentiate between benign and malignant skin lesions [2] and that it may not be possible to differentiate between cutaneous melanoma and scar tissue [3]. Hence tissue characterization techniques that use quantitative parameters to classify tissues are worth investigating. In this work we focus on attenuation of ultrasound as a parameter for characterizing normal skin layers. Since the goal of tissue characterization of skin would be to aid noninvasive evaluation of lesions, thereby minimizing the need for biopsy procedures, estimation of tissue parameters needs to be done in vivo. The goal of this work is to obtain attenuation properties of (normal) human skin layers in vivo, to compare different layers, and also to study variations in properties from one site to another. Such body-site variations if any could indicate differences in the underlying collagen structure of dermis, or differences in skin tension at the locations [4].

Skin consists of a superficial layer of epidermis and an underlying layer of dermis. The region beneath the dermis consists of subcutaneous fat, which is sometimes considered as a third layer of skin and is referred to as hypodermis. In most parts of the body the epidermis is very thin compared to the dermis (0.15 mm vs. 1.2-1.8 mm). At the range of frequencies and pulse lengths typically used in high frequency imaging of skin, in most parts of the body only the dermis and subcutaneous fat are accessible for tissue characterization studies. However, at the palms and soles the epidermis is much thicker due to the thickened stratum corneum and is therefore accessible. Therefore by collecting data from fingertip and forearm regions we study not only variation in tissue properties with body-site but also study the ultrasonic properties of the thick fingertip epidermis.

II. METHODS

Experimental system

The experimental system used is shown in Fig 1. It consists of a PVDF transducer (Panametrics), a pulser/receiver (Panametrics, Model 5900), a digitizing oscilloscope (Tektronix, Model TDS

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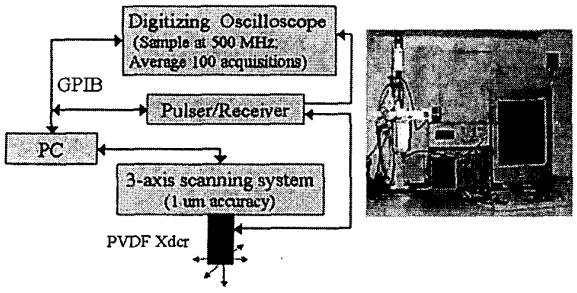

Figure 1: Experimental system

520C), a 3-axis scanning system (Parker-Daedal), and a PC to control mechanical scanning and GPIB-based data acquisition. Two transducers whose specifications are shown in Table I were used in this study. Because of its better sensitivity, the first transducer was used for most of the studies in this work and the second transducer was used to make sure that similar results are obtained from different transducers. The digitizing oscilloscope sampled the backscattered signals at a sampling frequency of 500 MHz. The scope also averaged several acquisitions (100 and 240 for transducers I and II respectively) to record A-scans with high signal-to-noise ratio. The transducer was mounted on a 3-axis stage that had encoders on the x and y axes to enable a high positioning accuracy of 1 μm. Lateral scanning by a distance of 0.6 mm was done to collect data from 25 independent locations in a 5 by 5 raster format along x and y axes. Water was used as a coupling medium between the transducers and tissues.

Table 1: Transducers used in the study

Transducer	I (Model PI50)	II (Model PI3005)
Freq. Range	10-45 MHz	20-55 MHz
F-number	2	2
Focal length	12.7 mm	4 mm

Diffraction elimination

Both the transducers were well focused (lateral resolutions of 0.1 mm and 0.075 mm), and therefore only data from the focal regions were used in analysis. To obtain data from different depths, the transducers were axially translated toward the tissue in several steps while signals were recorded from the focal zone at each position.

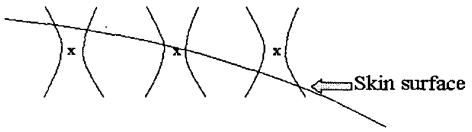

Figure 2: Surface curvature could affect lateral averages.

One problem that occurs with in vivo data collection is that since the skin is left to be free in its natural state, the surface may not be horizontal. As illustrated in Fig 2, this could lead to the focal zone moving out of the surface, or deep into the surface depending on the curvature. Spectra from adjacent locations cannot be averaged as such. Hence at each lateral location the system first detects the surface by comparing the strong surface echo with the background noise level, and adjusts the height of the transducer from the surface to a constant value before any axial scan is done. All axial scans were first done at a given lateral location before the transducer was stepped to the next lateral location.

Human subjects and tissues studied

Sixteen young right-handed adults (aged 19-34) were used in this study. Data were obtained from 3 different sites in the body using the first transducer: Dorsal side of right forearm near the wrist, dorsal side of right forearm near the elbow, and left index fingertip. Due to their proximity the two forearm regions can be expected to show similar results, thereby serving the role of a control study. In the case of skin regions near the wrist and elbow, data were collected from 10 focal zones via axial translation starting from 0.3 mm up to 3.0 mm depth in steps of 0.3 mm, which covered both the dermis and fat. In the case of fingertip, 12 focal zones were used from 0.3 mm up to 1.95 mm in steps of 0.15 mm, which covered both epidermis and dermis. Signals from subcutaneous fat at the fingertip were too weak to be studied. At the forearm wrist region alone the second transducer was also used. Two independent repetitions were done for each subject at each location to increase the sample size in determining variations across subjects.

Attenuation estimation

Signals from all the focal zones in the tissue were gated (0.2 μs), hamming-windowed, and Fourier-

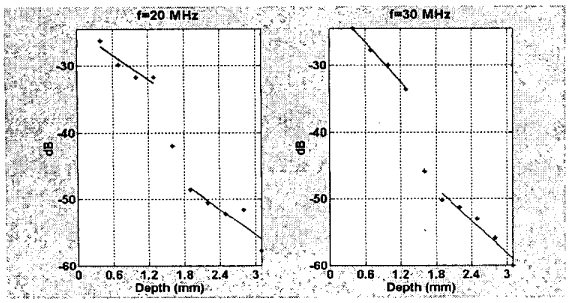

Figure 3: Computation of spectral slopes at two frequencies (20 and 30 MHz) for the forearm wrist skin.

transformed to compute power spectra and averaged with those from all lateral locations to compute mean spectra. Fig 3 illustrates the computation of spectral slopes in dB/mm at the forearm wrist for the 10 focal zones from 0.3 mm to 3 mm. The rapid drop in signal level at about 1.5 mm indicates the transition between the upper dermis and lower fat. Slopes for the dermal and fat regions were computed at several frequencies. In order to describe the dependence of attenuation with frequency, a linear fit of the following form was done in all cases:

$$\alpha(f) = \beta * (f - 25) + C \qquad (1)$$

In the above expression β is the attenuation coefficient in dB/mm/MHz and C is the attenuation in dB/mm at 25 MHz. In this work we will refer to the spectral slope simply as 'attenuation' (dB/mm) and β as 'attenuation coefficient'. Additionally, a power-law fit was also done for the case of forearm wrist dermis after the mean attenuation vs. frequency data were combined from both the transducers:

$$\alpha(f) = af^n + b \qquad (2)$$

Difficulties

One difficulty in computing attenuation using in vivo backscatter techniques is that it is not possible to differentiate genuine attenuation loss from drop in signal level simply due to decrease in scattering properties between the depths. Another problem is that since the experiment takes about 6 minutes, hydration effects can affect the results.

III. RESULTS AND DISCUSSION

Forearm dermis

Fig. 4 shows the attenuation in forearm dermis measured using the 2 transducers. It can be seen that in the overlapping frequency range of the two transducers, the results match well. The attenuation coefficients obtained by a linear fit for the first and second transducers were 0.21 and 0.23 dB/mm/MHz respectively. The increase in value for the higher frequency transducer suggests a possible power law behavior. When the mean data from both the transducers were combined and fitted to the power law function (Eq. 2), an exponent of 1.2 was obtained. However the goodness of fit for both linear and power-law fits were identical (correlation coefficient=0.99) and hence in subsequent results only the simpler linear model was used.

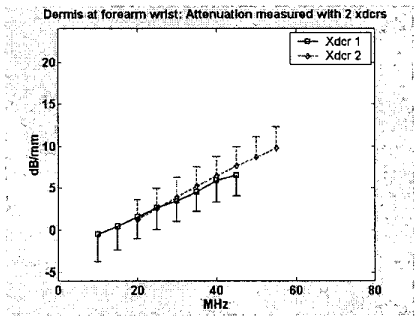

Figure 4: Attenuation by forearm wrist dermis measured using 2 transducers. The error bars indicate standard deviation across subjects, and only one side of the bar is shown for clarity.

Attenuation by dermis at different body sites

Table II summarizes the results from all tissues and locations. Fig 5 also shows the attenuation in dermis at the 3 locations: fingertip, forearm wrist and forearm elbow. It can be seen that while the attenuation at the two forearm locations are similar, the one at the fingertip is higher compared to the other two. Looking at the numerical values in Table II, it can be seen that it is possible to separate dermis at the fingertip from that at the forearm using the attenuation value at 25 MHz (C).

Dermis vs. subcutaneous fat at the forearm

It can be seen from Table II, that fat at each of the two forearm regions has a similar attenuation coefficient (β) as the corresponding dermis, but has a higher value of attenuation at 25 MHz on the average. However given the relatively high standard deviations it was not possible to reliably distinguish between dermis and fat by using a single threshold value that was valid for all subjects.

Table II: Summary of results. β is the attenuation coefficient in dB/mm/MHz and C is the attenuation at 25 MHz in dB/mm.

Tissue	Location	β	C
Dermis	Fingertip	0.32±0.12	9.5±2.6
	Forearm wrist	0.21±0.07	2.6±2.5
	Forearm elbow	0.20±0.06	1.8±2.1
Subcutaneous fat	Forearm wrist	0.19±0.13	4.5±2.8
	Forearm elbow	0.18±0.1	4.2±2.1
Epidermis	Fingertip	0.19±0.39	26±10.3

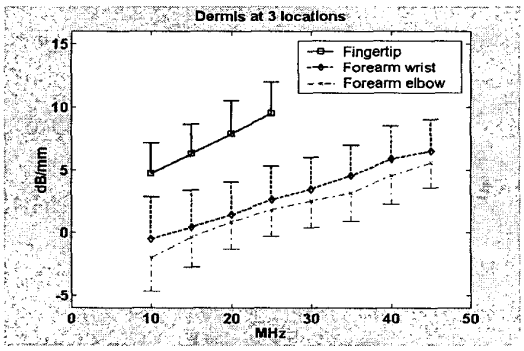

Figure 5: Variation in dermal attenuation with body-site. Due to increasing noise only data up to 25 MHz was used for the fingertip dermis.

Epidermis vs. dermis at the fingertip

Fingertip epidermis shows a very high value of attenuation without a proportionate increase in β. In order to investigate this further we obtained B-scan images at the fingertip (Fig 6) that showed a multi-layered inhomogeneity for the epidermis. Since in computing the attenuation values the entire epidermis was assumed to be homogeneous, it is likely that the computed attenuation values reflect decreases in scattering properties due to inhomogeneities rather than attenuation. Similar effects are possible for dermis and fat but perhaps not to the extent observed for epidermis.

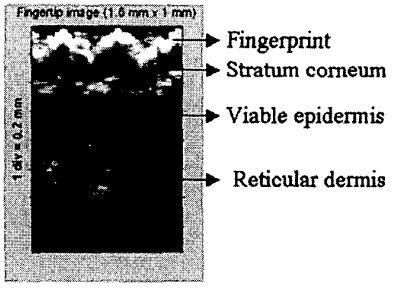

Figure 6: In vivo image of a fingertip.

SUMMARY

Attenuation of high frequency ultrasound as a function of frequency has been obtained in vivo for human dermis and subcutaneous fat. The studies indicate that there are systematic variations in attenuation in the dermis at different body sites. Also no significant differences in attenuation between the dermis and fat were observed. Epidermis at the fingertip showed an inhomogeneous-layered structure that needs to be analyzed further. These results are expected to be useful in further studies in high frequency ultrasonic characterization of healthy and diseased skin.

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