High-Resolution 3D MR Elastography of Human Skin

S. Maderwald[1], F. Stock[1], C. J. Galban[1], R. Jeyrani[1], K. Uffmann[1], A. Liffers[2], H. H. Quick[1], M. E. Ladd[1]

[1]Department of Diagnostic and Interventional Radiology, University Hospital Essen, Essen, Germany, [2]Institute of High Frequency Engineering, Ruhr-University Bochum, Bochum, Germany

Introduction:

Magnetic resonance elastography (MRE) is a phase contrast-based method for observing shear waves propagating in a material to determine its stiffness. In vivo studies in skeletal muscle, in the breast, and in the brain have already demonstrated the feasibility of this method. In this work, we applied MRE to quantify elasticity in the dermis and subcutaneous fat. The long-term aim of this project is to characterize melanoma, to obtain information on age dependence, and to evaluate the effects of skin creams by studying wave propagation in the skin. To visualize structures within the skin requires high in-plane spatial resolution of about 40-100 µm. To achieve high SNR in such tiny voxels, the use of a dedicated surface receive coil is mandatory, and a 3D acquisition scheme provides higher SNR than a 2D strategy.

Methods and Materials

A 1.5 Tesla scanner (SIEMENS Magnetom Sonata) equipped with high performance gradients capable of 40 mT/m maximum amplitude and a slew rate of 200 mT/m/ms and a custom surface coil (Fig. 1) [1] were used. This receive-only coil was developed for high-resolution in vivo imaging of human skin. The coil consists of a very low noise, 2-turn, 18mm-diameter loop. A modified 3D phase contrast (PC) sequence with motion-sensitizing gradients (MSG) was implemented for imaging. To induce mechanical waves into the region of interest, a piezoelectric oscillator [2] was used. The mechanical excitation was performed with a frequency of 250 Hz and an amplitude of 600 µm. The oscillator lever was mechanically attached to the dermis via a Plexiglas appendage oscillating in the right to left direction relative to the forearm of the subject. In the region of interest, all 19 (11 men, 8 women) volunteers (mean age 40, range 27 to 56) showed no skin abnormalities. The local frequency estimation (LFE) technique was used to determine the shear wavelength in the dermis and the subcutaneous fat and, from this, the shear modulus of the tissue [3]. For the LFE reconstruction, the LFE mean of eight phase offsets relative to the induced motion was used after sorting and phase unwrapping each 3D dataset. Image postprocessing was performed using Matlab (R13, The MathWorks, Natick, MA). The total scan time for the phase offsets with motion-encoding direction parallel to the direction of induced motion was approximately 4:20 minutes. Parameter settings for the modified 3D PC sequence were TR/TE 64/14.5 ms, flip angle 15°, FOV 25 x 25 mm^2, slice thickness 1.5 mm, 8 sagittal slices, BW 200 Hz/pixel, in-plane matrix 128 x 64 interpolated to 256 x 128. Two MSG cycles in the partition direction with an amplitude of 30 mT/m were applied.

Results:

Sufficient SNR was provided by the RF coil and the 3D imaging sequence for imaging of healthy skin in all volunteers. The examination time of 15 minutes for setup, localization scans, and MRE measurements was easily tolerated by all volunteers. However, positioning may have to be modified in a patient population, since the volunteers were placed prone with their arms extended over their heads. The averaged elasticity value, represented by the shear modulus, was 1.97 ± 0.07 kPa and 2.47 ± 0.07 kPa for dermis and subcutaneous fat, respectively. No differences between genders were found in the forearm region, and no statistically significant trends in the elasticity values as a function of age could be determined in this limited group.

Fig. 1: Size comparison of the coil with a 1 cent coin.

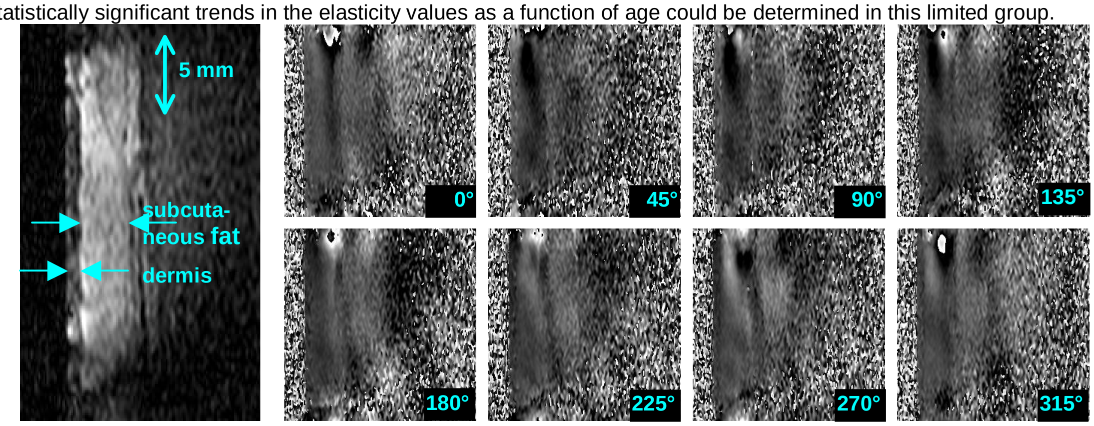

Fig. 2: Sagittal PC3D magnitude image of the dermis and the subcutaneous fat. The corresponding phase images with different phase offsets (0°-315°). Wave propagation through the tissue is conspicuous.

Discussion:

The present study clearly demonstrates that high-resolution MRE of human skin is feasible with the combination of a modified 3D phase contrast sequence and a dedicated surface coil. The results for subcutaneous fat match roughly with published results in ultrasonic dynamic elastography [4], but the results for the dermis are significantly out of the range of other published results, which vary from Pa to MPa [5], where the elasticity was measured with ultrasound or by mechanical means. Insufficient resolution of wave propagation in the extremely thin dermal layer, combined with reconstruction issues, may explain this difference. To achieve even higher SNR and spatial resolution, the use of 2- or 3-element phased array surface coils would be desirable [6]. Furthermore, the 3D PC acquisition scheme can potentially provide a complete dataset with motion sensitizing in all three spatial directions to reconstruct the full elasticity tensor. This tensor could potentially yield important additional information about the tissue structure and provide more accurate elasticity reconstruction, especially in an anisotropic material like the dermis. However, this approach suffers from very long scan times, since the acquisition time is trebled. For volunteers it would be very difficult to keep still for such a long time, and it is clearly unacceptable or impossible for patients in clinical routine. Further investigations should be done to prove the feasibility of the method for the characterization of melanoma, influence of aging, or the effects of skin cosmetics.

References:

[1] Liffers, A., et al., High Resolution in Vivo MRI of the Skin and Comparison to High Frequency Ultrasound, ISMRM 2000 Proc. p.1400
[2] Uffmann, K., et al. Design of an MR-compatible piezoelectric actuator for MR elastography. Concepts in Magnetic Resonance 2002;15(4):239 - 254.
[3] Manduca, A., et al. Image Processing for Magnetic Resonance Elastography. SPIE 1996;2710:161 - 623.
[4] Gennisson, J.L., et al., Assessment of Elastic Parameters of Human Skin Using Dynamic Elastography. IEEE 2004, Vol.51: 980 - 989.
[5] Khatyr, F., et al., Model of the viscoelastic behaviour of skin in vivo and study of anisotropy. Skin Research and Technology 2004, 10:96 - 103.
[6] Liffers, A, et al., Phased-Array Coils for MR Microscopy of the Skin in vivo, ISMRM 2002 Proc. p. 864