Characterization of Lesion Surface Properties utilizing the Transverse Strain Energy

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Synopsis

The evaluation of the shear strain energy in dynamic steady-state MR-Elastography allows to obtain information about the surface characteristics of lesions. This effect is caused by the dependency of mode conversion on the properties of the interface between the surrounding tissue and the lesion.

Introduction

Currently, Elastography is used as a new technique for the characterization of tissue as well as of lesions via the assessment of viscoelastic parameters [1]. The source of contrast for the reconstruction of these parameters is in dynamic steady-state MR-Elastography (MRE) a sinusoidal acoustic wave-field at frequencies around 100 Hz. The total wave-field consists of two separate fields with very different physical properties: the compressional wave-field propagating at the speed of sound (about 1550 m/s in soft tissue) and the shear wave-field (about 1 m/s). The latter represents the source of information required for the reconstruction of the shear modulus as well as the shear viscosity. One way to efficiently illuminate the object with shear waves is to utilize the effect of mode conversion, i.e. the transfer of energy from the compressional to the shear mode (and vice versa) at boundaries and interfaces. Breast lesions are characterized by viscoelastic alterations of local tissue properties. Thus, they represent sources for mode conversion minutely depending upon their surface as well as their internal architecture. This property should lead to characteristic effects visible in the transverse fraction of the strain energy. Thereby, the analysis of this fraction might provide additional insight into the surface characteristics of breast lesions.

Methods

MRE measurements on patients were performed in conjunction with standard MR-Mammography using Gadolinium as contrast agent. The MRE-sequence captures the steady-state acoustic wave-field (85 Hz) at 8 instances during one oscillatory cycle for all three spatial displacement directions. These information are used to evaluate the displacement vector at each location, i.e. $u_i = A_i \cos(\omega t + \varphi_i)$, with A_i the local amplitude and φ_i the local phase of the *i*-th displacement component. The local strain energy is defined by the following expression:

$$E = \frac{\lambda}{2}(u_{ii})^2 + \mu(u_{ik})^2 \quad , \qquad (1)$$

with u_{ik} the strain tensor. The almost incompressible nature of tissue prevents a precise evaluation of the quantity u_{ii}, i.e. the calculation of the compressional contribution to the strain energy. However, the shear contribution ($E^{shear} = \mu(u_{ik})^2$) can safely be calculated. The shear modulus calculation is done utilizing the method presented in [2]. The sinusoidal modulation in time allows to simply evaluate the time-integral of the shear strain energy over one period of the oscillation.

Results

Fig.1b shows the resulting shear strain energy for a fibroadenoma. The presence of the lesion leads to a significant drop in E^{strain} at the centre of the lesion. A significant increase of E^{strain} is well visible exactly located at the surface of the lesion giving rise to a ring-like structure encompassing it. This effect is caused by mode-conversion of compressional energy into shear energy at the surface. Fig. 1d shows the corresponding results for an infiltrating ductal carcinoma. Again, a similar drop of the shear strain energy is observed in the centre of the lesion. Differently, no ring-like structure of enhanced shear strain energy is visible. This is probably caused by the different surface of the carcinoma when compared to the previous example of the fibroadenoma. Its irregular surface leads to a less efficient mode conversion and thus to less generation of shear waves.

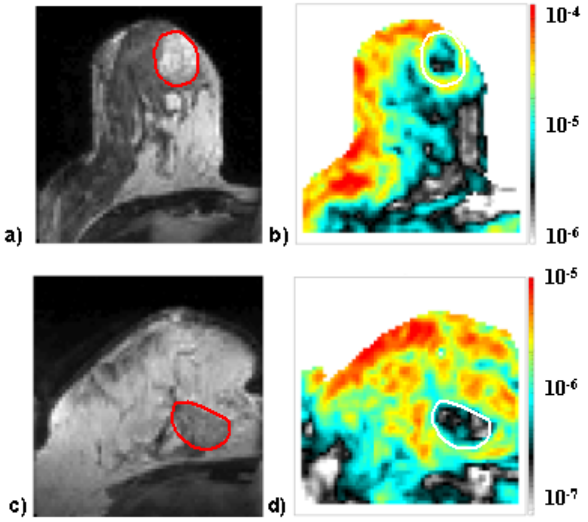

Fig1: MR-magnitude images of a fibroadenoma a) and a carcinoma c) (red lines). b) and d) Corresponding images of the shear strain energy. Here, the corresponding boundaries of the lesions are marked by white lines.

Discussion

The calculation of the shear strain energy is feasible when performing 3D steady-state MR-Elastography. The analysis of its topology in relation to the lesion morphology has the potential to provide information about the surface architecture of lesions. This can be helpful for the classification whether a lesion is well-circumscribed or rather spicular.

References

[1] Muthupillai et al., 1995 Science 26 1854-7

[2] Sinkus et. al, MRI 2004 (in press)