# Revealing the origin of attenuation in tissue: pure absorption or multiple scattering?

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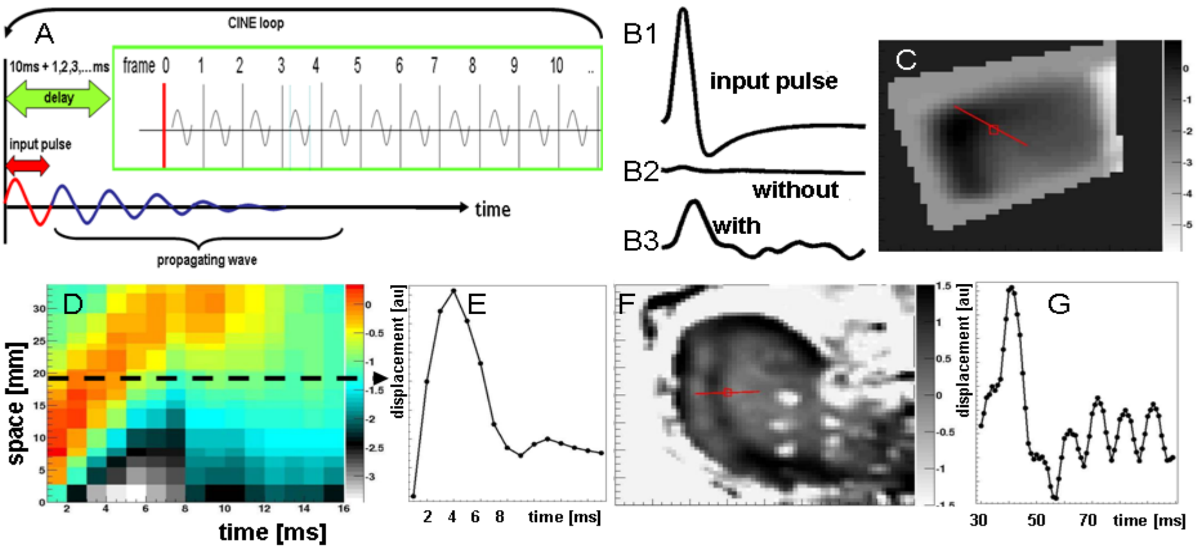
**Introduction:** It is only recently that we have had access to in-vivo mechanical properties of tissue via MR-elastography techniques. Inversion of the 3D mechanical wave equation provides values for the complex shear modulus G* which are independent of any hypotheses on the underlying rheological model. In general a power-law behaviour is observed for G* in the frequency domain with exponents deviating considerably from unity [1,2]. This behaviour cannot be explained via simple rheological models, interpretable in the mechanical setting as an arrangement of springs and dashpots. Hierarchical models have been proposed [3] but they do not provide any further insight into the true origin of the observed physical effect. Multiple scattering theories are however able to relate the spatial distribution of reflection coefficients, i.e. scatterers, to the observed dispersion behaviour of G* [4,5]. To justify the applicability of such a theory to tissue, it is mandatory to first investigate whether very-short-delay multiple reflections occur in tissue. Theory predicts notably different temporal pulse shapes as a response to a broad-band impulse depending on the presence/absence of those reflections. The presence of multiple reflections in liver tissue is proven for the first time via single breath hold transient MR-elastography and their absence shown in a silicon phantom.

**Methods:** A 2D CINE FFE sequence (TE/TR=6/9ms) with 30 frames was extended by adding a 200Hz bipolar gradient to render the sequence sensitive to motion (Fig.A). At the beginning of each CINE cycle, one single mechanical push at a selected frequency (50Hz for liver and 200Hz for the silicon phantom) was applied to the object. Data acquisition time for a $64^2$ matrix was 20secs (hence feasible within one single breath hold). Changing the delay (here 10ms) between mechanical push and beginning of the CINE train allowed obtaining virtually any temporal resolution of the propagating wave train (here 1ms between each consecutive frame). Theoretical results for a broad-band input pulse (Fig.B1) showed very different pulse shapes for materials w/o very-short-delay multiple reflections (Figs.B2,B3). Experiments were performed in a homogenous silicon phantom and the liver of a healthy volunteer using a 1.5T full body scanner (Philips Medical Systems, Best, The Netherlands).

**Results:** Fig.C shows the image of the propagating wave after (10+1)ms in the silicon gel. The corresponding time-space diagram along the red line in Fig.C is shown in Fig.D. It is obvious that predominately the positive lobe of the input impulse is transmitted into the strongly absorbing silicon gel. The pulse shape at position 20mm in Fig.D (dashed line, red rectangle in Fig. C) is shown in Fig.E. Evidently, the negative lobe of the input impulse is strongly attenuated and no further coda is registered. Fig. F shows a snapshot of the propagating wave after (10+31)ms in the human liver. The red rectangle in Fig.F indicates the position of the pulse signal shown in Fig.G. Clearly, positive and negative lobes are visible together with a long coda. Those results agree with the theoretical predictions shown in Figs.B2,B3 for materials w/o very-short-delay multiple reflections.




**Discussion:** At present, the origin of the power-law behaviour of the tissues' complex shear modulus in the frequency domain is not understood. Hierarchical rheological models provide heuristic solutions, but no physical understanding. On the contrary, theories based upon multiple scattering do provide explanations which in fact relate the distribution of the reflection coefficients, induced by for instance the presence of the vasculature, to the dispersion of mechanical waves. The applicability of such theories to tissue is however intimately linked to the question whether very-short-delay multiple reflections do actually occur. The present investigation gives a positive answer to this question. In the next steps it will be necessary to demonstrate that the predicted link between the distribution of reflection coefficients and the observed dispersive behaviour of G* indeed holds.

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