Preoperative Assessment of Meningioma Stiffness by MR Elastography

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Introduction: Meningiomas vary in stiffness and the ease of resection is in part determined by the consistency of the tumor. A noninvasive method for measuring tumor stiffness would improve preoperative planning and more accurately assess the risk of surgery. However, current imaging methods have limited ability to predict the mechanical properties of meningiomas [1]. Magnetic resonance elastography (MRE) is an MR technique to noninvasively measure tissue stiffness [2]. MRE begins by introducing shear waves into the tissue of interest with an external vibration source. The resulting shear wave motion is imaged with a phase-contrast MR pulse sequence with motion-encoding gradients synchronized to the externally applied motion. Finally, the shear wave images are mathematically inverted to calculate tissue stiffness. The feasibility of MRE to measure meningioma stiffness has been previously demonstrated [3]. The purpose of this work was to perform a pilot study to determine if MRE shows merit for measuring meningioma stiffness noninvasively.

Methods: MRE data were collected with a modified spin-echo EPI pulse sequence on a 3T MR imager (SIGNA Excite, GE Healthcare, Waukesha, WI). Shear waves at 60 Hz were introduced with a soft pillow-like driver placed under the head and imaged with the following parameters: TR/TE = 1500/61 ms, FOV=25.6 cm, 60x60 imaging matrix reconstructed to 64x64, 3x ASSET acceleration, 2.5-mm slices with a 1.5-mm spacing, one 4-G/cm motion-encoding gradient on each side of the refocusing RF pulse, x, y and z motion-encoding directions and 4 phase offsets over one period of motion. The curl of the wave images was calculated and stiffness was determined with a direct-inversion algorithm [4]. A 3D T1-weighted acquisition was also performed for each subject and the meningioma was traced on these high-resolution images. The meningioma mask was then registered and resliced to the MRE data. Two ROIs were calculated from this mask. The meningioma ROI was calculated by taking two serial erosions with a jack-shaped structural element to reduce edge artifacts. The surround or adjacent tissue ROI was calculated by dilating the mask twice with the jack-shaped structural element, subtracting the original mask and taking the intersection of this shell with a brain mask. The meningioma stiffness and the surrounding stiffness were entered into a multiple regression. MRE was performed on 13 meningiomas that went to surgery. One case was excluded due to small size (no voxels remained after the erosion step).

The surgeon (blind to the MRE results) made a note of the tumor consistency and recorded the results in the surgical record. The surgeon's qualitative assessment of tumor stiffness was then converted to a 5-point scale: soft (1), mostly soft (2), mostly firm (3), firm (4), and hard (5).

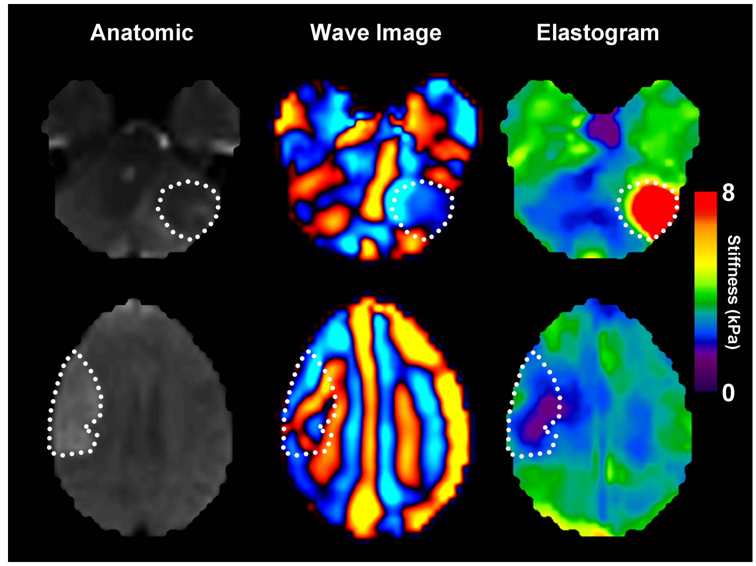

Figure 1. Example images from a subject with a firm meningioma (top row) and a subject with a soft meningioma (bottom row). The anatomic image is shown in the left column, an example wave image in the middle column and the resulting elastogram in the right column. The tumor border in each case is represented by the dashed lines.

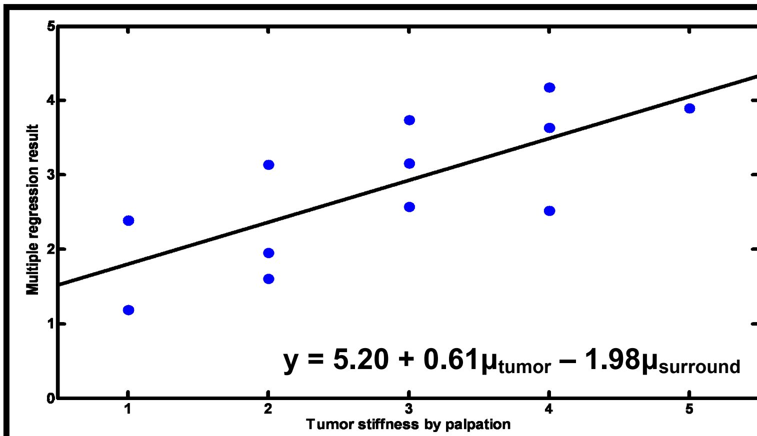

Figure 2. Scatter plot showing the result of the multiple regression versus tumor consistency as assessed by the neurosurgeon. Multiple regression showed that both meningioma stiffness ($p<0.01$) and surrounding stiffness ($p<0.05$) significantly correlated with tumor consistency.

Results: Example images from a firm and soft meningioma are shown in Figure 1. Multiple regression indicated that both meningioma stiffness ($p=0.0096$) and surrounding stiffness ($p=0.033$) significantly correlated with the qualitative assessment of tumor stiffness on the 5-point scale. The regression results are shown in Figure 2.

Discussion: As expected, tumor stiffness as measured by MRE significantly correlates with the surgeon's qualitative assessment of tumor stiffness by palpation during surgery. Surrounding stiffness negatively correlated with the surgical assessment. This correlation may indicate that stiff tumors in some way soften the surrounding brain parenchyma. Alternatively, this term may serve as compensation for any residual influence of the surrounding tissue on the measured tumor stiffness, as the inversion is effectively a low-pass filtered version of the true underlying stiffness. Overall MRE produced a metric that was significantly correlated with the surgeon's assessment of tumor stiffness and merits further investigation. In the future MRE may improve preoperative planning of meningioma resections.

References: [1] Hoover et al. Surg Neruol Int 2011. 2: 142. [2] Muthupillai et al. Science 1995. 269 (5232): 1854. [3] Xu et al. Acta Radiol 2007. 48 (3): 327. [4] Oliphant et al. Magn Reson Med 2001. 45: 299.