Measurement of acceleration-induced deformation of the human brain by MRI tagging

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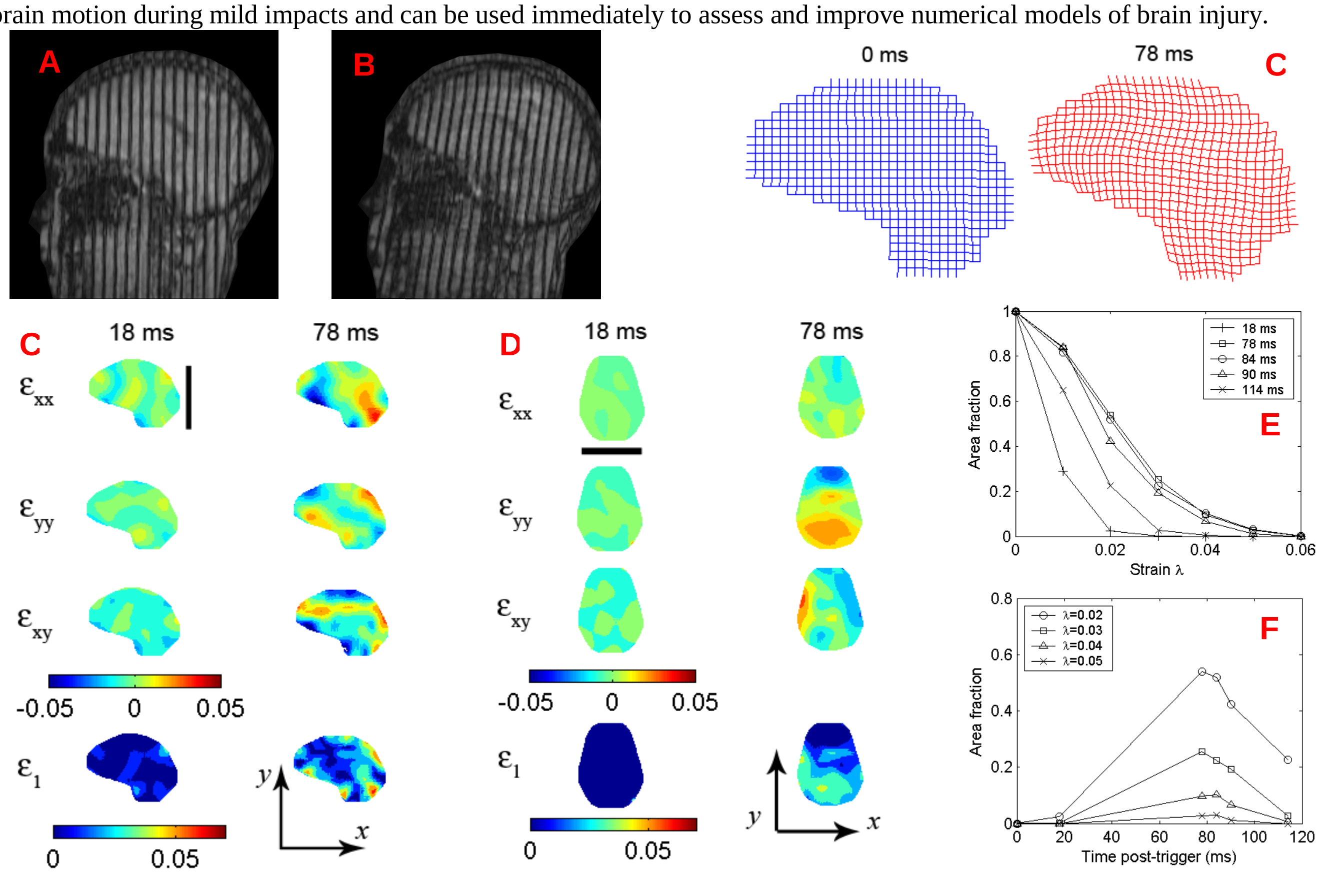
Background: Rapid deformation of the brain due to acceleration is the likely cause of concussion, as well as severe traumatic brain injury (TBI). The inability to measure deformation has led to confusion about the biomechanics of TBI [1]. MR tagging [2] and harmonic phase (HARP) analysis [3] are widely used to measure cardiac deformation, and are well-suited to study brain kinematics.
Methods: Human volunteers (n=3) performed controlled mild accelerations of the head inside a clinical MR scanner (Siemens Sonata 1.5T). The head of the supine subject was supported by an elastic pocket in a fiberglass frame. When the subject released a latch the frame would drop 2 cm and hit a plastic stop. Peak decelerations of 20-30 m/s^2 (2-3 Gs, ~landing from a short jump) were measured with a head-mounted accelerometer (PCB #336C04). The MR pulse sequence was triggered by an optical sensor upon latch release. Tag lines (SPAMM 1331, vertical, horizontal, or both) were applied, followed by a fast gradient-echo cine sequence (FLASH2D, TR=6 ms, TE=2.9 ms, 90 frames). Motion was repeated to obtain a 192x72 data matrix at each time point (1 k-space line per repetition). The protocol was approved by the Institutional Review Board of the Washington University School of Medicine. Image analysis was performed by a version of the HARP method [3]. The intersections of HARP phase contours were used to define vertices of a triangular mesh, in both reference images and deformed images. The local deformation gradient tensor F and the 2-D apparent Lagrangian strain tensor E were estimated from the deformations of corresponding triangles, assuming locally homogeneous strain.
Results: The brain deforms slightly but visibly under these accelerations (Figs. A-B). Deformation is seen more clearly in synthetic tag lines obtained via HARP with deformations scaled 5X (Fig. C). Strains of 2%-6% are seen in several regions after impact (Figs D-F). Images suggest that the brain is stretched as it pulls away from basal and frontal attachments, before it contacts the occipital skull.
Discussion: Quantitative measurement of strain in human subjects is feasible with MR tagging. These data increase understanding of brain motion during mild impacts and can be used immediately to assess and improve numerical models of brain injury.



Figures: (A) Reference (acquired immediately after triggering and tagging) and (B) deformed (78 ms later) SPAMM tagged images. (C) Deformed synthetic tag lines (HARP isophase contours) with deformation scaled by a factor of 5. (C-D) Apparent 2-D Lagrangian strain fields in sagittal and transverse planes. (E) Fraction of sagittal area in which max. principal Lagrangian strain exceeds a specified strain level, λ, plotted vs. λ, for several times. (F) This area fraction plotted vs time, for several strains λ.

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