TIME-LAG RADIOGRAPHIC ASSESSMENT OF BRAIN DISTORTION DURING HEAD IMPACT SIMULATION

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INTRODUCTION

Assessment of brain deformation and shear during head impacts is of central interest to understand traumatic brain injury (TBI) and to investigate head protective technology. Over the past decade, high-speed photography has been employed to directly capture deformation in skull hemi-spheres filled with brain-surrogate. More recently, Hardy et al. (2001) were the first to measure spatial brain distortion inside a complete human cadaveric skull by use of high-speed stereoradiography. We proposed a time-lag radiography approach to directly capture brain motion relative to the skull during head impact simulation. Compare to high-speed stereoradiography, this approach may allow capturing brain motion with standard radiography equipment, and does not require subtraction of superimposed skull kinematics from brain motion. This study investigated the feasibility of time-lag radiography on a surrogate model of the skull and brain.

METHODS

Time-lag radiography captures motion of radiodense tracer particles on an X-ray sensitive medium in form of time-lag streaks. These streaks reflect the magnitude and direction of tracer particle motion during the duration of time-lag exposure. To simulate brain distortion relative to the skull, a surrogate model based on the design and materials of Ivarsson et al. (2000) was fabricated (Figure 1). This model reflects a 100mm thick parasagittal cross-section of the human skull made of aluminum, which accounts for prominent anatomical structures. Brain was substituted with a silicone gel (Sylgard 527, Dow Corning, Midland, MI), which was confined in the skull between Plexiglas caps. Radiodense tracer particles, consisting of 1.5mm Ø lead spheres enclosed in PE foam were placed in a 2cm grid in the mid-section of the brain surrogate. The density of the composite tracers ($0.82 g/cm^3$) was less than that of the silicon gel ($0.97 g/cm^3$) to trace region-specific brain deformation without influencing deformation. An 8x10inch imaging plate (ST-VI, Fuji-film, Burbank, CA) with 0.1mm pixel size was rigidly connected to the skull to capture brain distortion in absence of superimposed skull motion. The head model was confined to rotation around a transverse axis. Rapid angular acceleration of the head around this axis was induced with an impact pendulum.

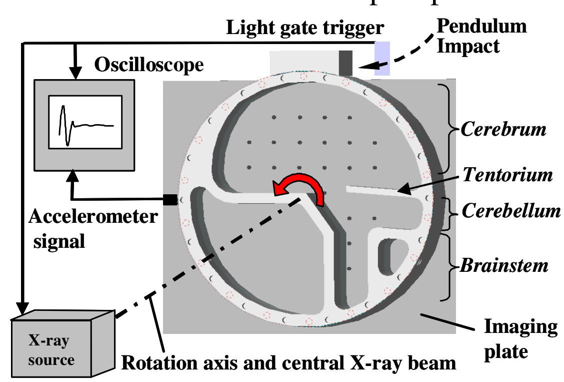

Figure 1: Time-lag radiography setup.

An X-ray source (GE AMX II, SOMA Tech., Cheshire, CT) was placed at 2m distance from the head model with its X-ray beam aligned with the rotation axis. The X-ray source was triggered by the pendulum by a light gate 10ms prior to impact. Time-lag exposure of 100ms duration at 110kVp and 10mAs during head acceleration projected time-lag streaks of tracer displacements relative to the skull on the imaging plate. Time-lag radiographs were enhanced by regional histogram equalization and analyzed with digital image analysis software (Matlab, MathWorks, Natick, MA) to quantify the magnitude and direction of time-lag streaks. Head acceleration was measured with an accelerometer (ACC103, Instrument Lab Inc., Oberlin, OH) and recorded with an oscilloscope (54603B HP, Palo Alto, CA) at 60kHz. Reproducibility of the technique was assessed on three time-lag radiographs, obtained at acceleration levels which did not yield irreversible deformation of the brain surrogate.

RESULTS

Pendulum impacts caused a head surrogate acceleration of 2380 ± 150rad/s^2 magnitude and 6.9 ± 0.6ms duration. Static projection of a reference lead sphere of 4mm Ø ensured that no relative motion between the imaging film and the skull surrogate occurred (Figure 2). Brain surrogate deformation relative to the skull was apparent by time-lag tracings with pronounced visibility of the initial position and reversal point of the makers. The smallest displacement magnitude was observed in the frontal lobe (C1, 0.5±0.2mm) (Table 1). The largest displacement occurred in the parietal lobe region (A4, 2.6±0.2mm). The direction of displacement was inhomogeneous and depicted a quasi-circular pattern. Deep layers (C1-6) translated in anterior and superior direction, while outer layers (A2-5, B4-6) translated in posterior and inferior direction.

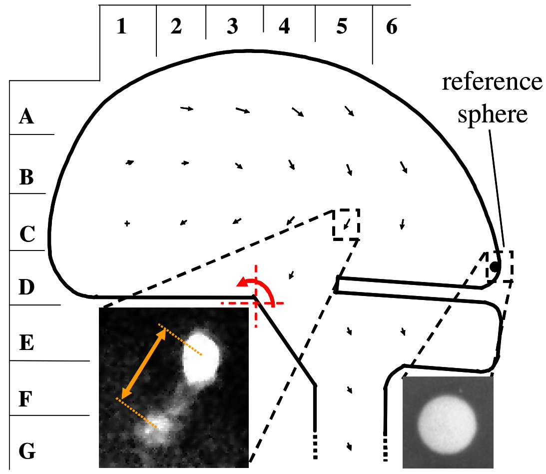

Fig. 2: Time-lag streaks and reference bead.

DISCUSSION

This study demonstrated feasibility and reproducibility of time-lag radiography for assessment of brain deformation during head acceleration. Results correlate to Ivarsson et al. (2002), who also noted opposing displacement patterns in outer brain layers compared to deep layers under rotational head acceleration. The present study was limited to 2.4 Krad/s^2 acceleration to preserve the surrogate brain for reproducibility testing. Due to absence of sampling rate limitations, this approach may be capable to capture brain deformation during injurious levels of rotational head acceleration in the range of 7-10 Krad/s^2.

REFERENCES

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ACKNOWLEDGMENTS

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Table 1: Region-specific displacement magnitudes

	1	2	3	4	5	6
A		1.8±0.1mm	1.8±0.2mm	2.6±0.2mm	2.2±0.1mm	
B	1.1±0.2mm	0.9±0.2mm	0.9±0.3mm	1.7±0.1mm	2.1±0.1mm	1.8±0.2mm
C	0.5±0.2mm	0.6±0.1mm	1.4±0.1mm	1.9±0.3mm	1.8±0.3mm	1.3±0.1mm
D				1.0±0.2mm		