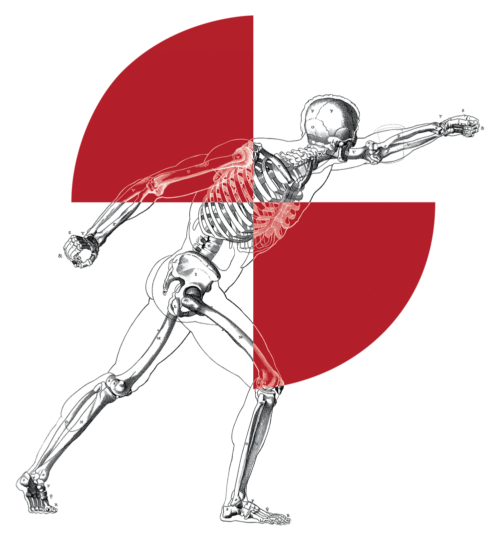

Ultrasound Measurement Validation Under High-Rate Rotational Motion

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INTRODUCTION

- Acute subdural hematoma is a lethal head injury with mortality rates cited up to 50%.[1] Understanding how the superficial brain moves relative to the skull during rotation is a crucial first step towards defining subdural injury risk
- High-frequency, B-mode ultrasound is advantageous for measuring superficial brain motion because it is non-invasive, and its high sound frequency allows for increased frame rate, better resolution, and the ability to capture high-speed motion
- Superficial brain displacement under rotation has been quantified and validated using a stationary, high-frequency, B-mode ultrasound probe[2,3]
- To obtain trackable brain motion images at higher rotation severities, the previous test setup was modified so that the ultrasound probe rotated with the head
- This study aimed to assess whether high-frequency, B-mode ultrasound will be able to accurately measure motion at the surface of the brain relative to the skull when the ultrasound probe is rotated with the head at high rates

MATERIALS & METHODS

- When the modified head rotation setup to used to measure brain displacement relative to the skull of a PMHS, the head is secured in a rotating fixture and the ultrasound probe is mounted to the fixture. This validation study utilized the same equipment for a direct comparison, with an ultrasound phantom in place of brain tissue (Figure 1)
- The validation fixture (Figure 2), mounted in the rotating fixture is comprised of an ultrasound phantom that is mounted to a shaft. A spring is loaded onto the shaft to limit the amount of motion of the phantom
- The target phantom motion for validation was between 1 and 4 mm, based on relative brain motion measured at rotational velocities and accelerations up to 26 rad/s and 3200 rad/s^2, respectively, in an initial PMHS trial. The spring stiffness was optimized to achieve the target motion
- Displacement of the phantom relative to the ultrasound probe was measured by a linear potentiometer that was rigidly mounted to the phantom
- The rotating fixture was rotated at rotational velocities between 21-33 rad/s
- Images of the motion of the phantom's embedded 3D printed peaks were collected using a VEVO 2100 ultrasound imaging system with a 550S probe
- Images were collected at a frame rate of 693 frames per second at an image width of 4.08 mm and a focal depth of 6 mm.
- Motion of the phantom in the US images was tracked using TEMA (Figure 3)

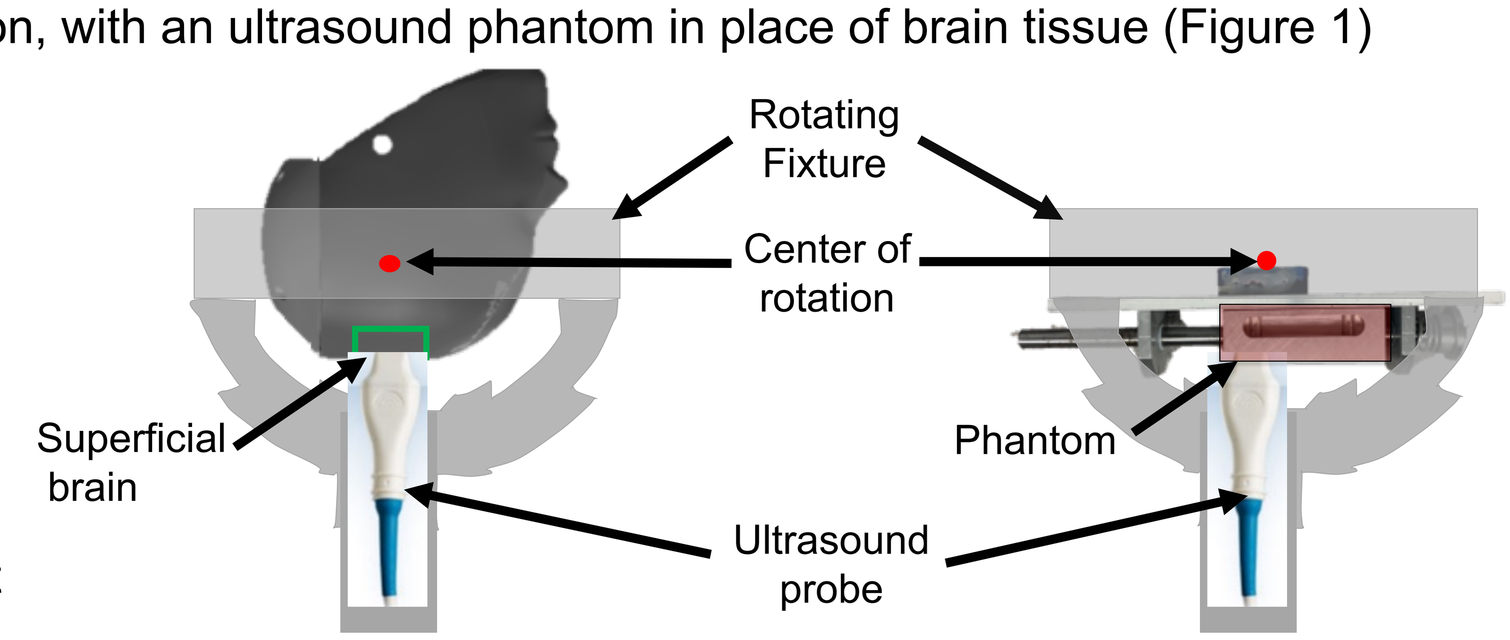


Figure 1:Modified PMHS test setup (left) and validation fixture in validation test setup (right)

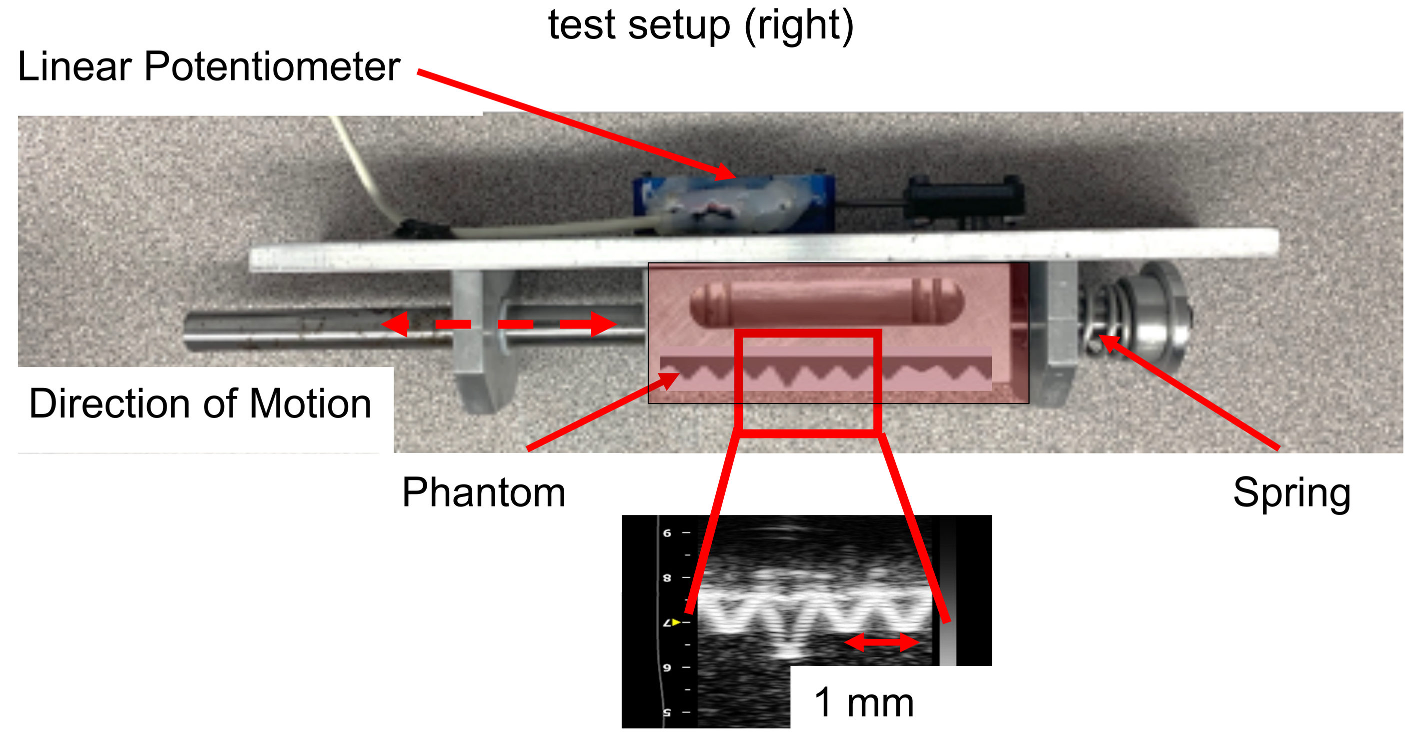


Figure 2: Validation fixture and ultrasound view

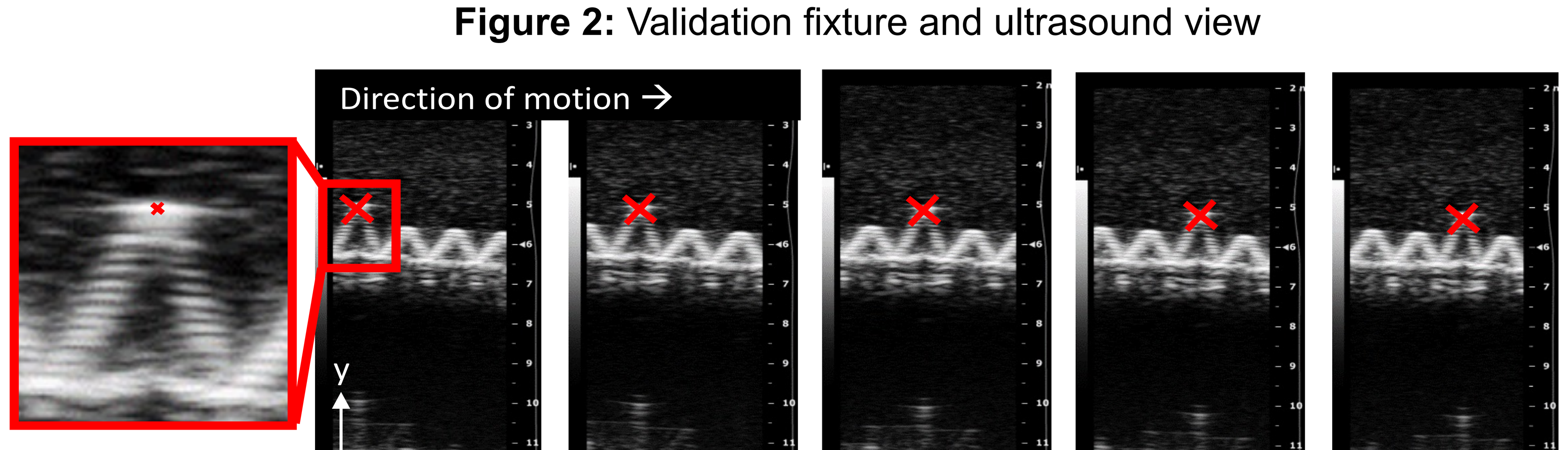
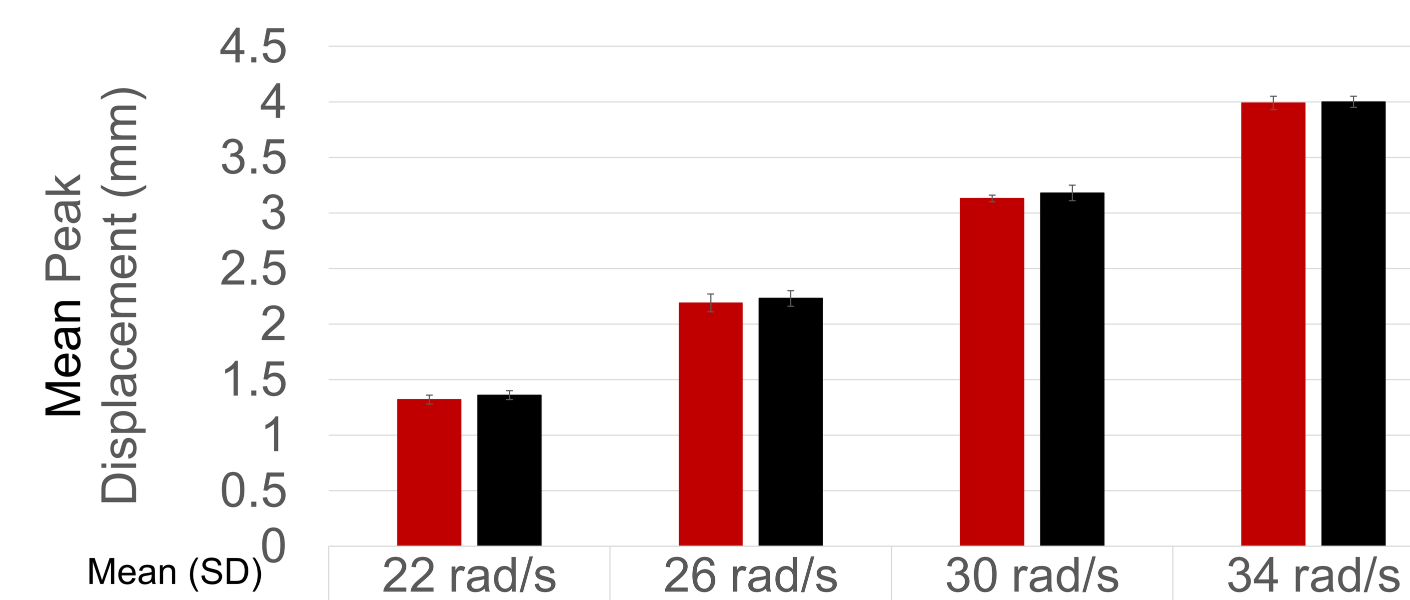


Figure 3: Ultrasound stills

RESULTS & DISCUSSION

- Mean peak displacements measured from the ultrasound and linear potentiometer were compared (Figure 4) and the percent difference in peak values was calculated relative to the potentiometer (Table 1)
- Peak displacements ranged from 1.32-4.00 mm at peak velocities between 22 and 34 rad/s and the US and pot showed similar results



Mean (SD)	22 rad/s	26 rad/s	30 rad/s	34 rad/s
Linear Pot	1.32 (0.04)	2.19 (0.08)	3.13 (0.03)	3.99 (0.06)
Ultrasound	1.36 (0.04)	2.13 (0.07)	3.18 (0.07)	4.00 (0.05)

Figure 4: Mean (SD) peak displacement comparison between linear potentiometer and ultrasound

- Root mean standard deviation (RMSD) is an indication of how closely the data matches along the entire time history curve with a value of 0 indicating a perfect match. RMSD values were calculated along the pulse and are summarized in Table 1.

Table 1: Comparison of displacement results: mean (SD)

Mean (SD)	22 rad/s	26 rad/s	30 rad/s	34 rad/s	AVG.
Mean % Difference in Peaks	3.36 (1.24)	1.91 (1.10)	1.57 (1.29)	1.04 (0.52)	1.97 (1.04)
Mean RMSD (mm)	0.04 (0.02)	0.05 (0.03)	0.05 (0.03)	0.09 (0.04)	0.06 (0.03)

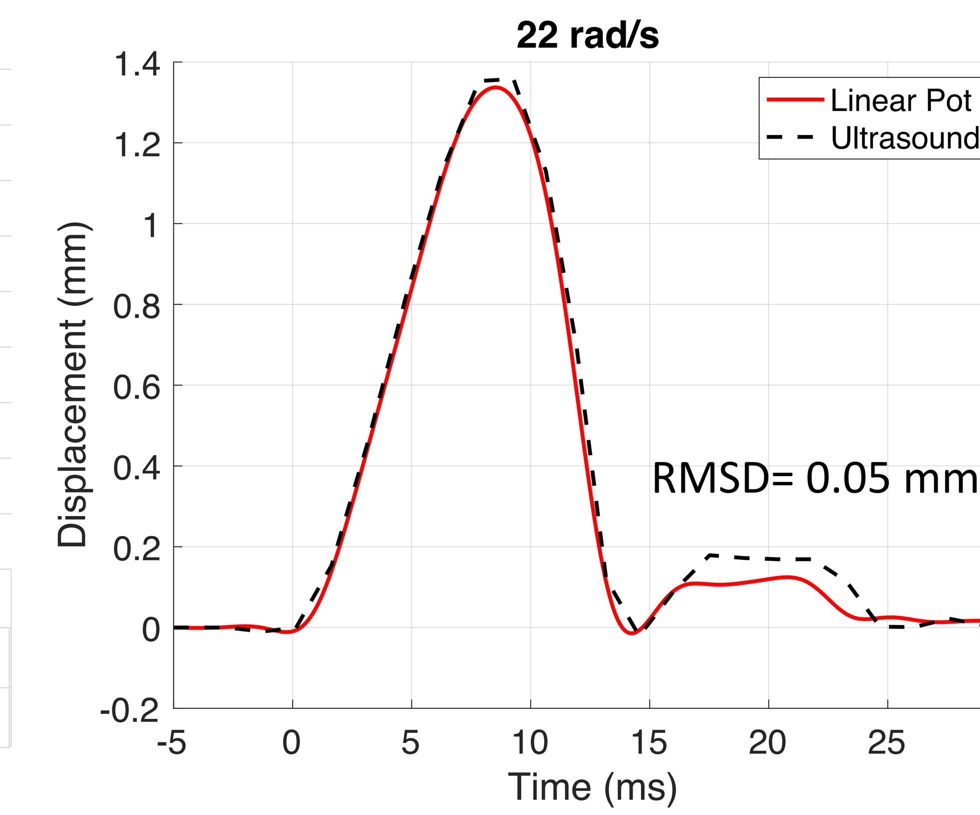
- Intra-observational error was calculated using the technical error of measurement (TEM)[4]

$$TEM = \sqrt{\frac{\sum D^2}{2N}}$$

where D is difference in the peak displacement measurement between the original and re-tracked tests and N is the number of repeat tests. The average TEM was 0.0115 mm indicating good repeatability.

- Work is ongoing to confirm the precision of the linear potentiometer that was used as the reference measurement in this study

- The average difference in peak displacement between the linear potentiometer and the ultrasound was less than 2%
- Ultrasound displacements were in the targeted range of 1 to 4 mm
- Exemplar time history data for 22 and 34 rad/s tests in the are shown in Figure 5



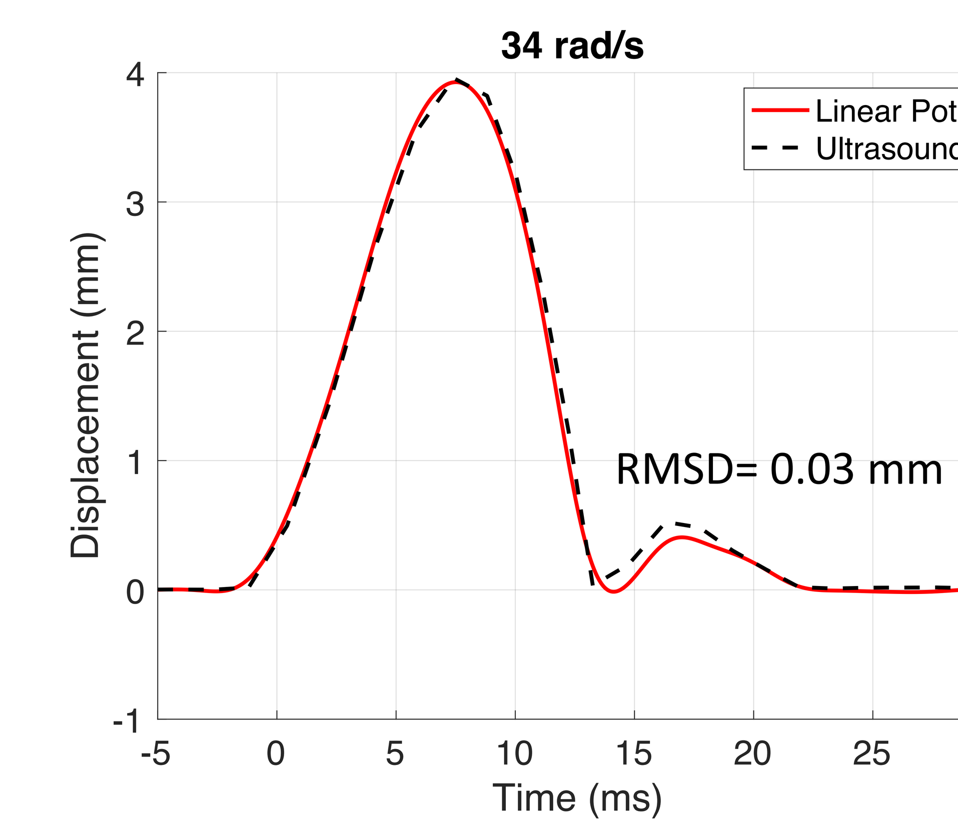


Figure 5: Displacement time history plots

CONCLUSIONS

- On average, the ultrasound measurement was within 2% of the reference measurement, with an average RMSD value of 0.06 mm, indicating that high-frequency B-mode ultrasound is a good option for quantifying brain motion when rotated at high rates with the head

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