Midline Shift vs. Mid-Surface Shift: Correlation with Outcome of Traumatic Brain Injuries

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Introduction

Why Traumatic Brain Injury (TBI)?

TBI is a major cause of death and disability, and it has a lifelong impact on patient health

Midline shift (MLS):

MLS is the max horizontal shift on the center line, and it is used to measure TBI severity. It has ambiguous results because MLS ignores much information on the image

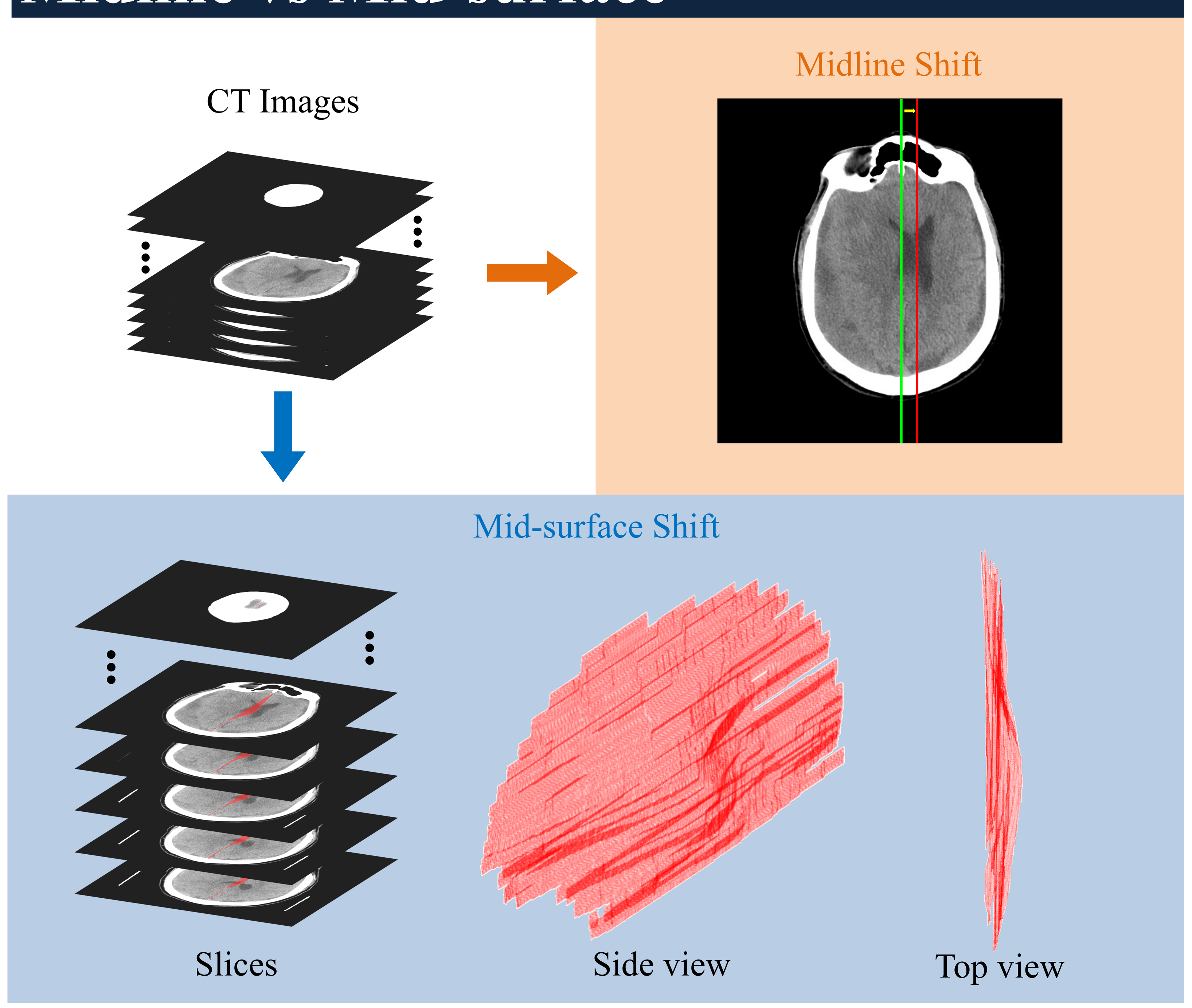
Goal:

We propose mid-surface shift (MSS) to better represent the deformation of the midline

Our Techniques:

Image Processing + Statistical Analysis

Midline vs Mid-surface



Glasgow Outcome Score (GOS)

GOS	Description	Classification
1	Death	Unfavorable
2	Persistent vegetative state	Unfavorable
3	Severe disability	Unfavorable
4	Moderate disability	Favorable
5	Low disability	Favorable

MSS Measurement

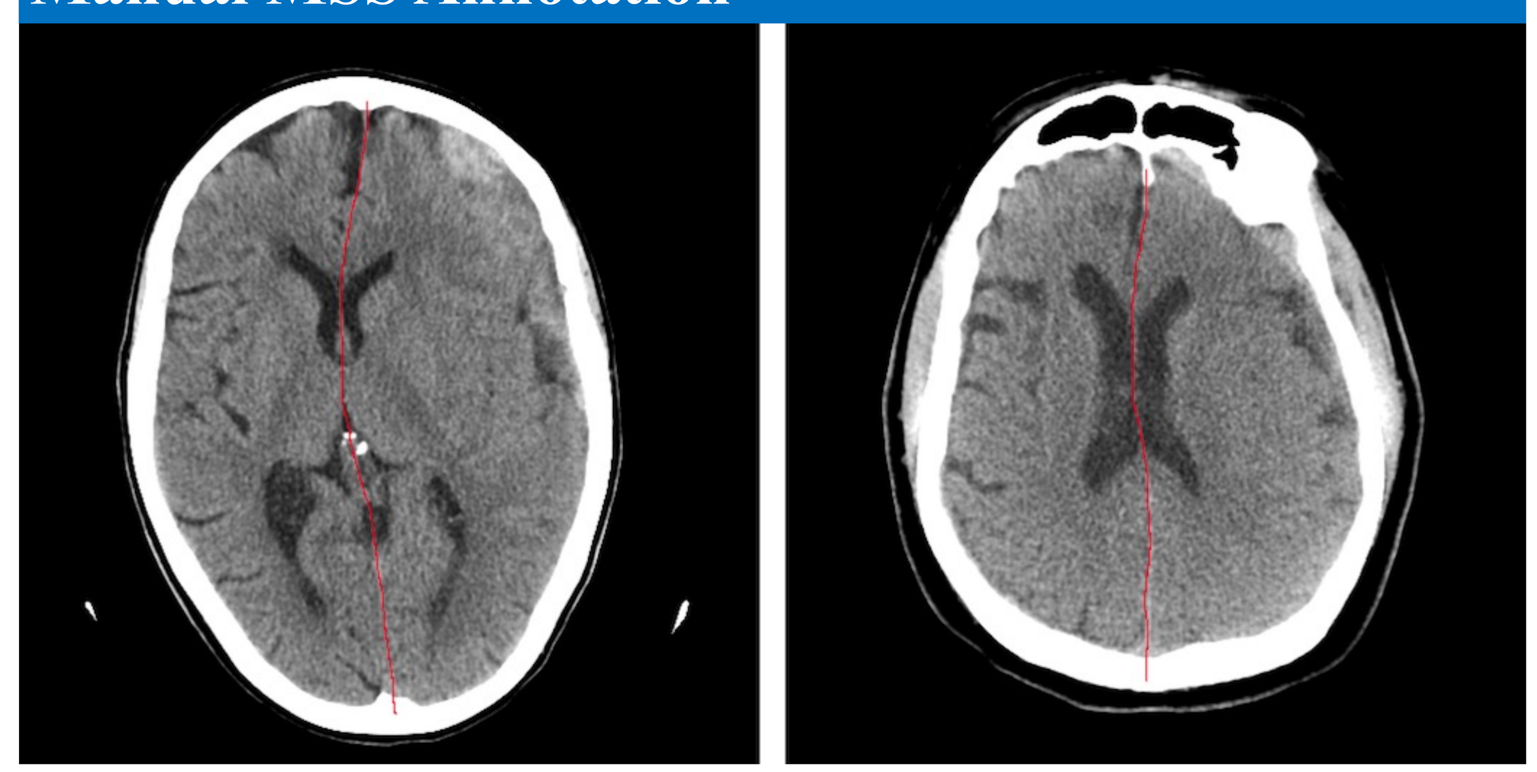
Automated Slice and Series Selection

Select CT series and slices suitable for analysis using metadata tags and image features

Series selection criteria:
- Contain only axial images
- Default window level is between 25 Hounsfield unit (HU) and 100 HU
- Slice thickness within the series closest to 5 mm

Slice selection criteria: brain area ≥ 90% of max brain area on a slice

Manual MSS Annotation



Annotation done manually using biomarkers in the brain, and the ratio between the volume of shift and brain volume is calculated:

$$\text{MSS} = \frac{\sum_{i=m}^{n} A_{\text{enclosed},i}}{\sum_{i=m}^{n} A_{\text{brain},i}}$$

$A_{\text{enclosed},i}$: the number of voxels enclosed by the annotated mid-surface and the ideal midline on the i^{th} slice
$A_{\text{brain},i}$: the brain mask area on the i^{th} slice.
m and n: the first and last selected slices, respectively

Patient Characteristics

Characteristics	Values, No.(%) or mean (SD) N = 48
Age, years	70.3 (13.7)
Male	27 (56%)
GCS on admission	13.8 (2.6)
Mild (GCS 13-15)	42 (88%)
Moderate (GCS 9-12)	2 (4%)
Severe (GCS 3-8)	4 (8%)
Charlson Comorbidity Index	2.2 (2.0)
Hematoma width, mm	13.0 (6.3)
Midline shift (MLS), mm	4.8 (4.8)
≥ 5 mm	19 (40%)
< 5 mm	29 (60%)

Results: Correlation with Outcome at Discharge

We expect a negative correlation between MSS/MLS and GOS

MSS and MLS vs. five GOS groups

We use Kendall's tau coefficient (τ) to measure the correlation between MSS/MLS and the 5 GOS groups, and point-biserial coefficient (r_{pb}) to measure the correlation between MSS/MLS and dichotomized GOS groups

Measurement	5 GOS Groups		Dichotomized GOS	
	τ coefficient	95 % CI	r_{pb} coefficient	95 % CI
MLS	-0.14	[0.341, 0.067]	-0.24	[-0.488, 0.051]
MSS	**-0.26**	**[-0.445, -0.073]**	**-0.31**	**[-0.542, -0.023]**

Dichotomizing MSS

We use Fisher's exact test to find the best threshold to dichotomize MSS while maximizing the correlation with dichotomized GOS groups

MSS threshold	Odds ratio	p-value
0.01	0.39	0.29
0.02	**0.30**	**0.05***
0.03	0.33	0.12
0.04	0.21	0.07
0.05	0.59	0.66

Dichotomized MSS and MLS vs. dichotomized GOS groups

We use Fisher's exact test to measure the correlation between dichotomized MSS/MLS and dichotomized GOS groups. MLS is dichotomized using a typical threshold of 5 mm

Measurement	Odds ratio	p-value
MLS	-0.36	0.14
MSS	**-0.30**	**0.05***

Results: Logistic Regression Analysis

We trained logistic regression classifiers to predict GOS at discharge using MSS/MLS, age, and GCS on admission. The two latter features are known to be important predictor of TBI outcome

Model	Sens.	Spec.	AUC	Acc.	Prec.	F1
+ MLS	0.71	0.57	0.65	0.64	0.63	0.67
+ MSS	**0.86**	**0.71**	**0.7**	**0.79**	**0.75**	**0.80**

Future Steps

- Further validate MSS performance on more data from more cohorts
- Design automated algorithms to quantify MSS

Conclusion

- We evaluated 2 brain structure shift measurements: midline shift (MLS) and mid-surface shift (MSS)
- We discovered that MSS correlations with patient outcomes are stronger than the MLS manual annotation