Development of a Biofidelic Upper Cervical Spine Model for Use in an Omnidirectional Surrogate Neck

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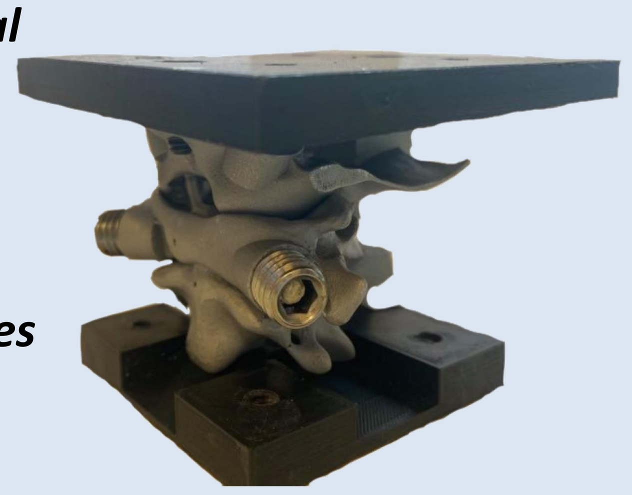
OBJECTIVE

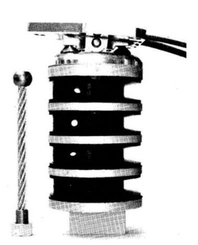
Develop an omnidirectional biofidelic upper cervical spine surrogate (C0-C2) by replicating the geometry and mechanical properties of key anatomical structures for the eventual development of a full ATD neck.



INTRODUCTION

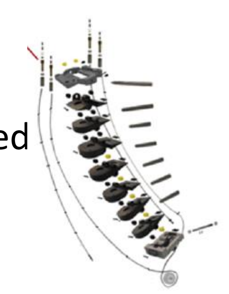
- Anthropomorphic test devices (ATDs) are used for the design of safety equipment that we rely on in our day to day lives.
- ATD necks are designed only for a specific loading scenario and their response is typically biofidelic only in that application.

Hybrid III (1977)
Biofidelic in: High speed inertial loading in the sagittal plane [1]

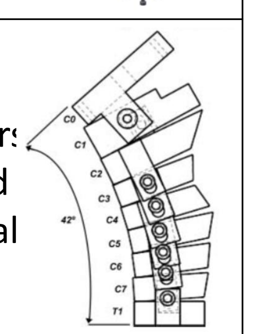


THOR (1996)
Biofidelic in: High speed inertial loading in the sagittal and frontal planes [4]

BioRid (1999)
Biofidelic in: Low speed inertial loading in the sagittal plane [2]

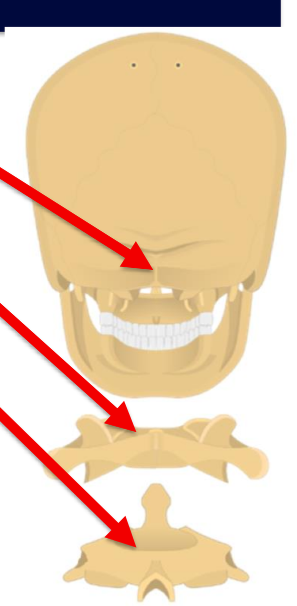


UBC Neck (2010)
Biofidelic in: Head first impacts and induced motion in the sagittal plane[6]



CONSTRUCTION - VERTEBRAE

C0	Portion on the base of the skull that interfaces with C1
C1 (atlas)	Upper facets facilitate flexion-extension, lower facets facilitate axial rotation
C2 (axis)	Contains the dens which is a proturbence about which C1 rotates axially

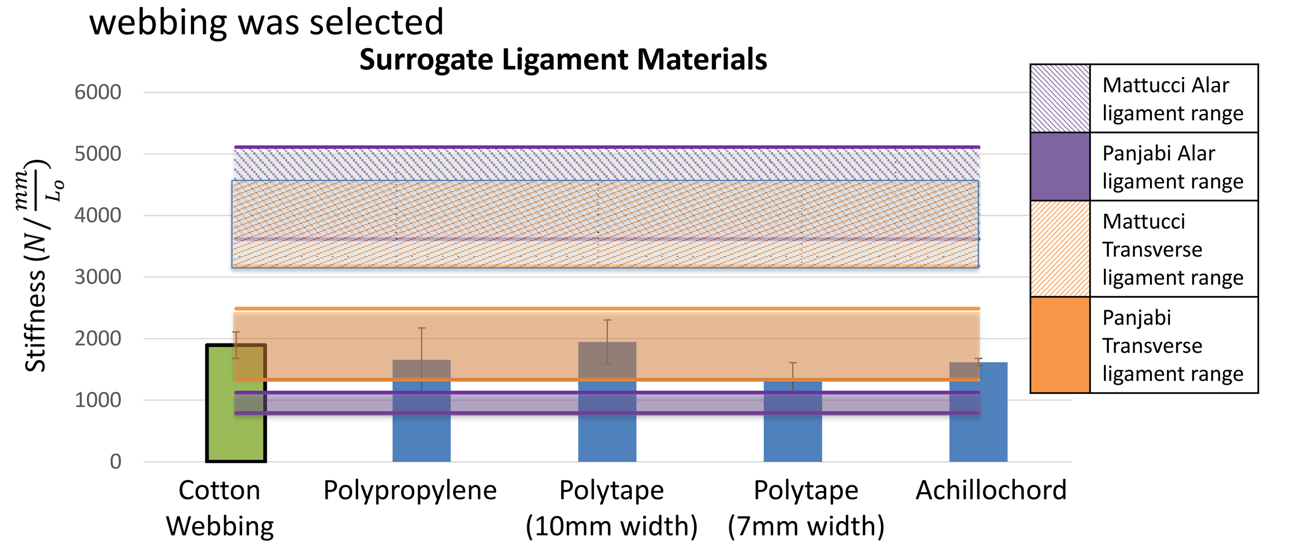


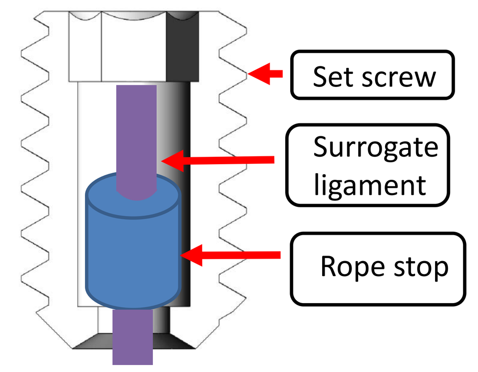
- CT scans from 31-year old male segmented and 3D printed in aluminum
- Vertebrae were realigned from supine scans to plausible seated neutral position

CONSTRUCTION - LIGAMENTS

Alar ligament	Passes from dens to C0 and limits flexion, lateral bending and axial rotation
Transverse Ligament	Passes across the foramen of C1 and holds the arch of C1 close to the dens to allow axial rotation
Nuchal Ligament	Passes along the posterior edge of all vertebrae and limits flexion

- Candidate materials for ligament surrogates were tested in uni-axial tension and compared to stiffness of cadaveric ligaments. A cotton webbing was selected

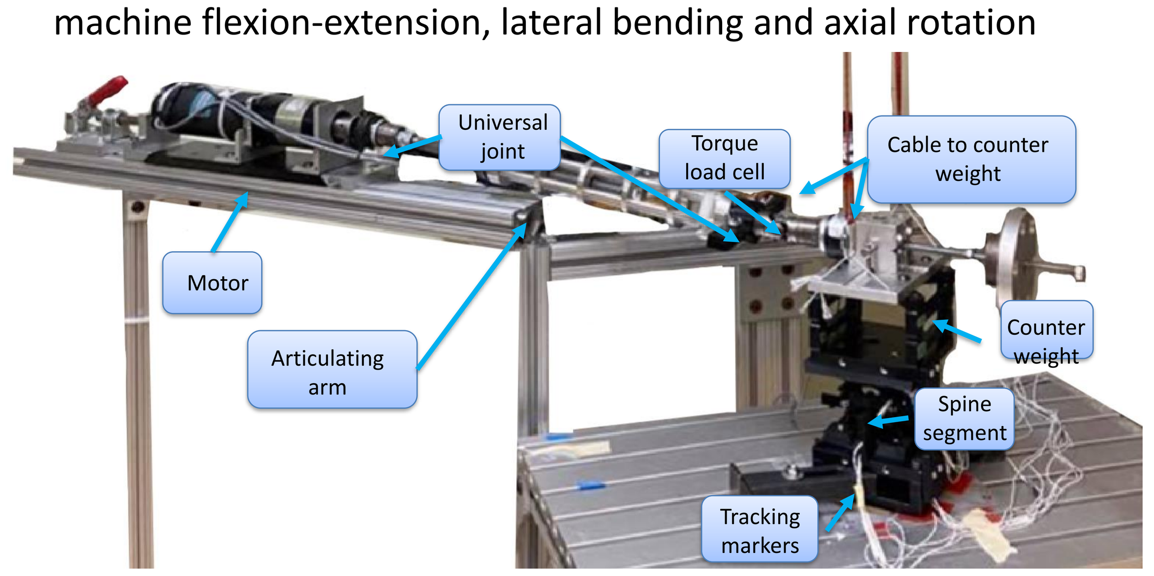




- Ligament tension was set by using a torque limiting screw driver to tighten set screws with the surrogate ligament material inset

TEST METHOD

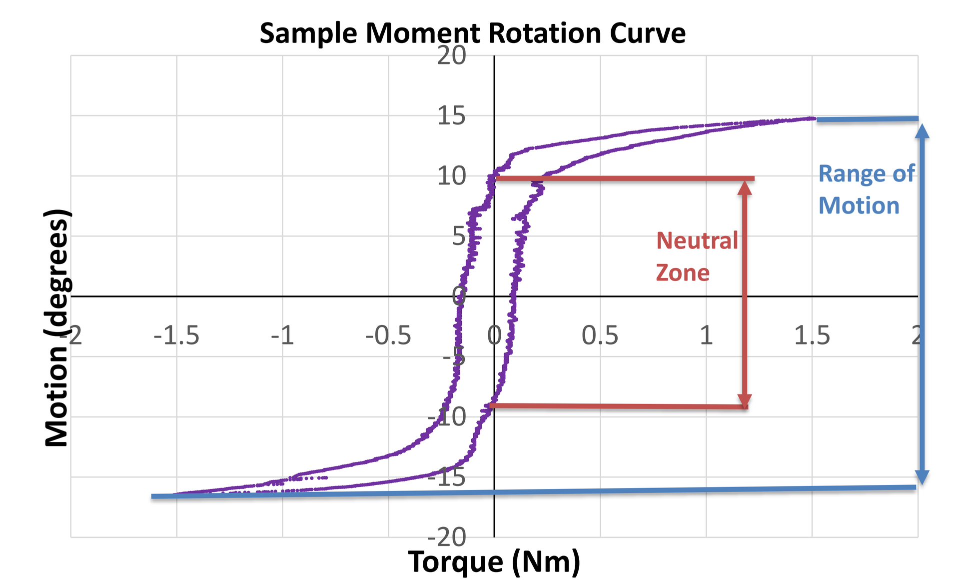
- Pure moment applied in quasi static loading with custom spine machine flexion-extension, lateral bending and axial rotation



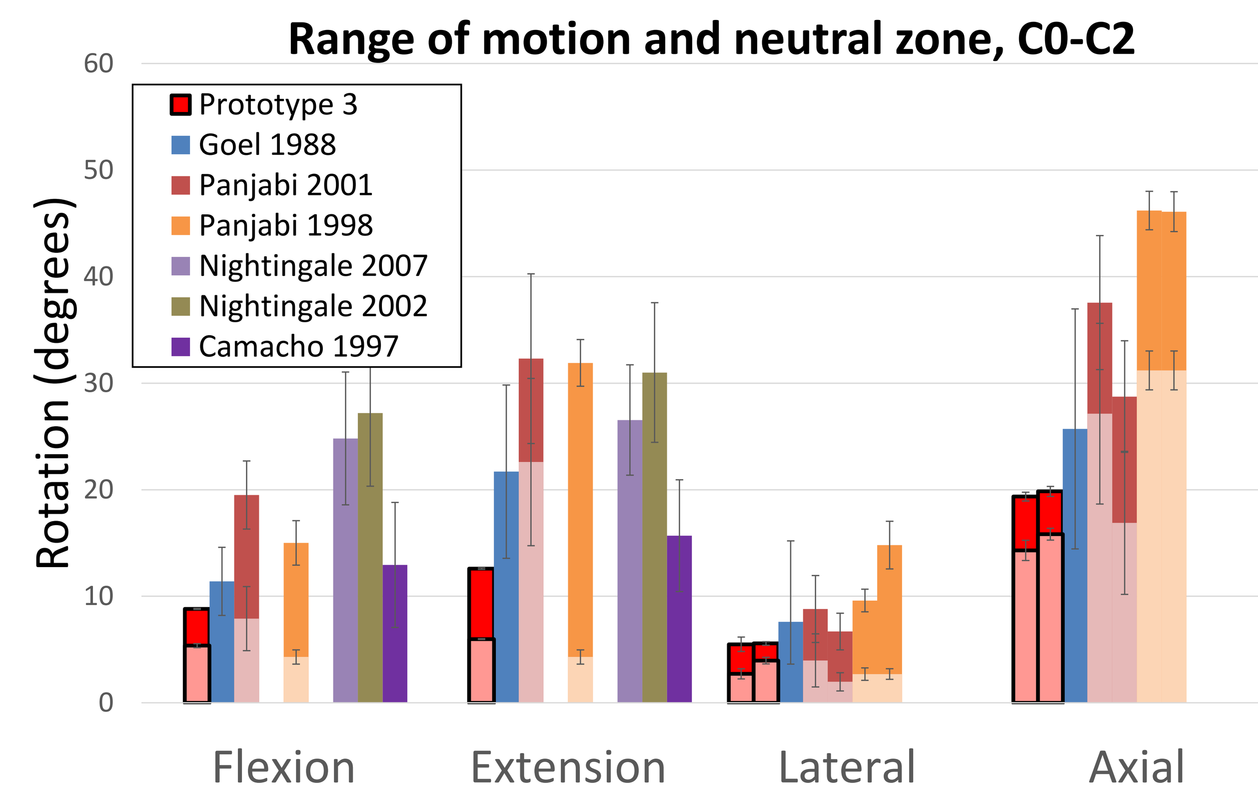
- Metrics are extracted from the applied torque and recorded kinematics

Range of Motion	Rotation at maximum applied torque
Neutral Zone	Residual rotation at zero applied torque
Helical axis of motion	Axis about which vertebrae rotate and translate

RESULTS



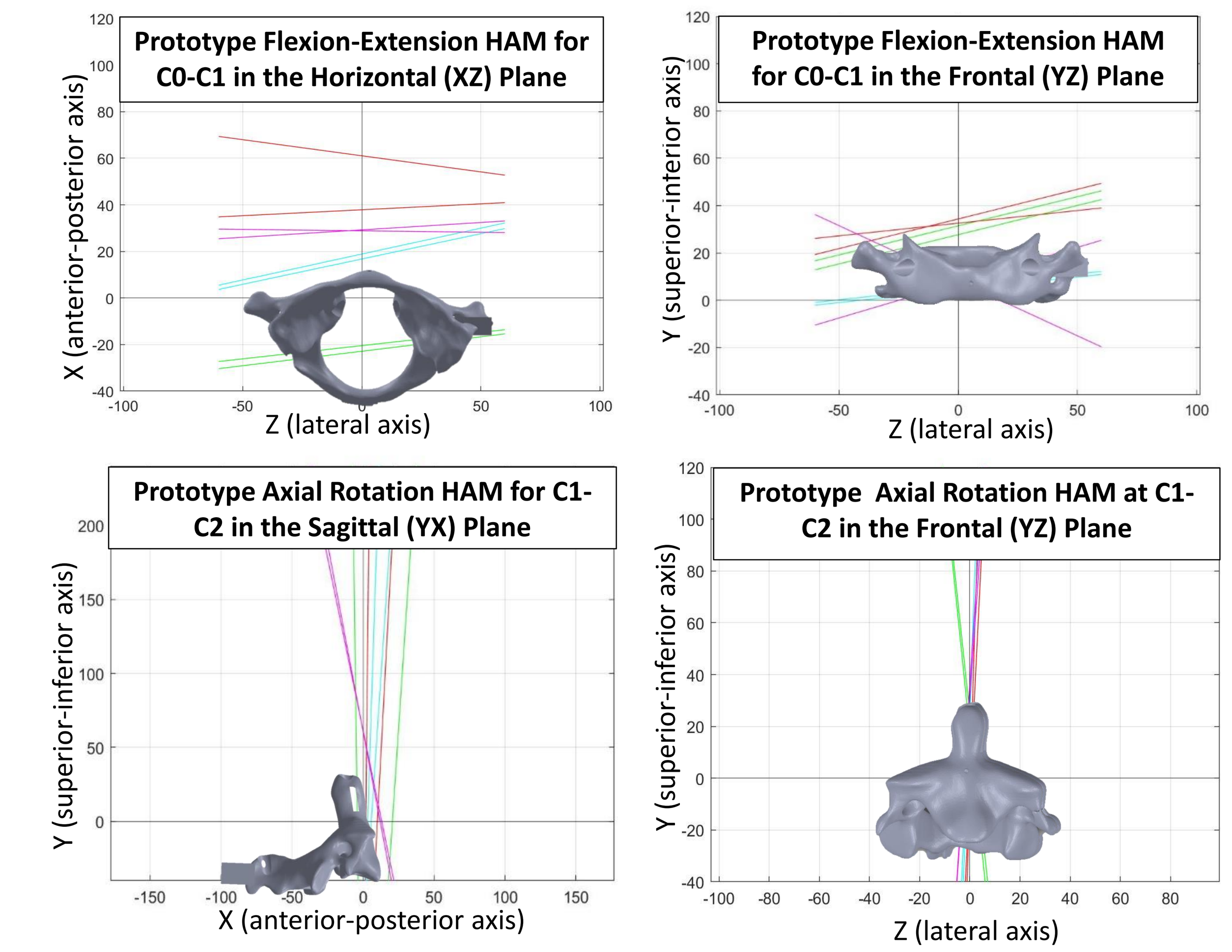
- Range of motion is presented in the darker colour and neutral zone in the superimposed lighter colour. The results of this study are in red



- Correlation and Analysis 4.0.4 software (CORA) was used to quantitatively asses the response of the prototype to the reference PMHS moment-rotation curves from the literature.
- Curves are give a combined score based how well they fit within the corridor, phase shift, size and shape
- Scores are given on a scale of 0-1 with $x<0.84$ being excellent, $0.65<x<0.84$ being good and $0.44<x<0.65$ being fair

	Flexion-Extension	Lateral Bending	Axial Rotation
C0-C2	0.74	0.84	0.48
C0-C1	0.58	0.83	0.62
C1-C2	0.71	0.89	0.60

- Helical axis of motion in 2D is plotted with vertebrae super imposed for context
- Each colour is a different reassembly trial



CONCLUSIONS

- Range of motion and neutral zone are within the reported ranges from cadaveric literature
- CORA scores all range from fair to excellent
- Lower scores in axial rotation and flexion-extension were due primarily to low phase shift scores. In axial rotation this indicates uneven distribution between left and right axial rotation, in flexion-extension, poor distribution between flexion and extension
- Helical axis of motion in axial rotation is aligned with the dens which is in line with what we expect as C1 pivots about this point. In flexion extension, helical axis is situated slightly more anterior to the occipital condyles about which C0 pivots
- This indicates that this approach is an effective way to replicate the quasi-static kinematics of the upper cervical spine and may be a useful tool in the development of a total omnidirectional surrogate neck

ACKNOWLEDGEMENTS AND REFERENCES

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