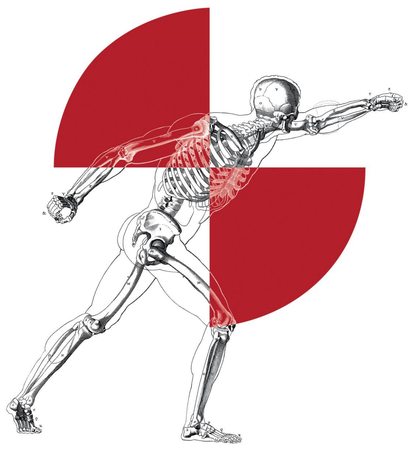

Validation of a Custom Head Fixture for Pediatric Cervical Spine Strength and Stiffness Assessment

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INTRODUCTION

- Pediatric cervical spine injuries account for roughly 10% of all cervical spine injuries across all age groups.[1–3]
- Anatomical differences in children may account for this increased vulnerability of the cervical spine (c-spine).[1,4]
- The broad objective of this research is to quantify biomechanical responses of the c-spine in children 5–7 years old to aid and improve the biofidelity of pediatric human body models (HBM) and anthropomorphic test devices (ATD).
- However, this task is not possible without the development of a custom fixture that allows the quantification of c-spine biomechanics.
- This study is focused on the validation of a custom head fixture to quantify volunteer c-spine biomechanics.

MATERIALS & METHODS

- A custom head fixture was designed and machined as an attachment to a Biodex Isokinetic Dynamometer to quantify c-spine strength and stiffness of pediatric volunteers in the anterior-posterior (AP) and lateral directions (Figure 1).

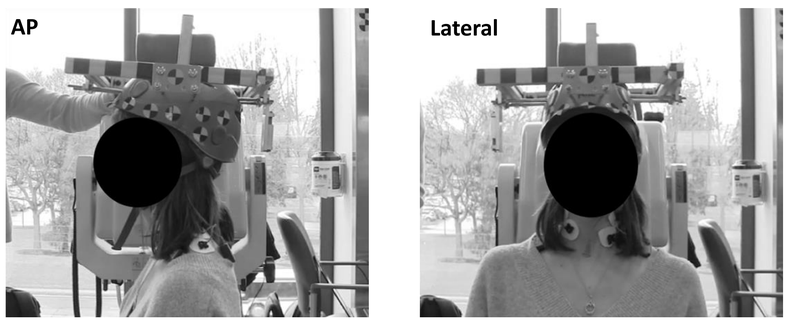

Figure 1: Custom head fixture mounted on the Biodex Isokinetic Dynamometer arm. Left: Subject seated in the AP direction of motion. Right: Subject seated in the lateral direction of motion.

- Validation of the fixture was performed in 2 phases to better understand the usability of the custom head fixture.

Phase I

Mechanical Validation

Evaluated in "worst-case" scenarios with increased speed and increased range of motion.

- Artifact interference
- Load distribution
- Repeatability

If the head fixture showed repeatable and consistent behavior, the head fixture was deemed safe for next step of validation.

Phase II

Fixture Validation with an Adult Cohort

Evaluation of self-selected snug and loose helmet fits. Subject efforts were assessed with surface electromyography (sEMG) on the sternocleidomastoid and upper trapezius muscles. Direction order was randomized.

- Isometric strength measurements with maximum subject efforts
- Stiffness measurements
  - 5°/s (with no effort)
  - 30°/s (with maximum effort)

Measurement accuracy was determined by comparing measurements outputs within the adult subjects and to available literature.[5,6]

RESULTS

Phase I

- Fixture-only "worst-case" scenarios showed artifact interference only at end of motion for all directions.
- Repeatable measurements showed slight differences in load distribution and negligible peak torque differences due to chosen equipment sensitivity (Figure 2).

Phase II

- Five female volunteers (25.8 ± 5.8 years) participated.
- Loose fit helmets had minimally larger displacements (<10mm) of the helmet relative to each subject's head in both directions.
- Helmet fit did not influence peak torque generation between subjects (Table 1, Figure 3).
- Helmet fit did not influence subjects' ability to engage with the testing equipment.
- For all subjects, sEMG recordings showed negligible differences in muscle activation between helmet fits.
- Overall torque differences between helmet fit type were within 0.11–1.08 Nm for all subjects in both directions.
- Differences in torque production were more influenced due to helmet shape than helmet fit.

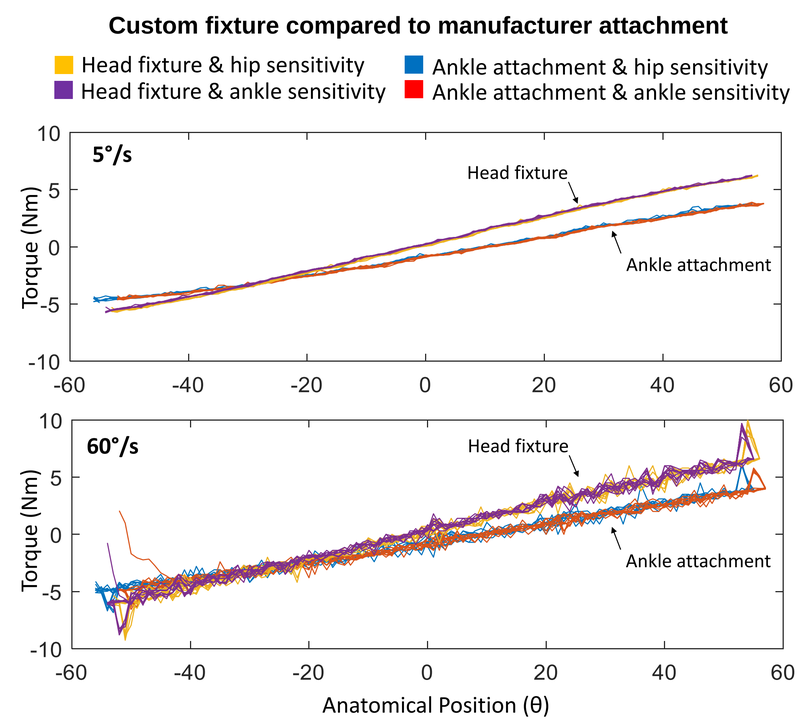

Figure 2: Torque output comparison between the custom head fixture and the manufacturer provided ankle attachment. Top: 5°/s velocity. Bottom: 60°/s velocity.

Table 1. Peak Torques Per Helmet Fit

	AP Direction				Lateral Direction			
Subject and Helmet fit	Peak Torque Flex. (Nm)	Peak Torque Ext. (Nm)	Δ Peak Torque (Nm)	Helmet Fit ΔTorque (Nm)	Peak Torque Right (Nm)	Peak Torque Left (Nm)	Δ Peak Torque (Nm)	Helmet Fit ΔTorque (Nm)
A01_L	8.20	13.16	4.96	0.44	12.33	11.68	0.66	0.18
A01_S	11.08	15.60	4.52		14.78	13.93	0.84	
A02_L	10.20	11.97	1.77	0.55	10.25	10.38	0.13	0.91
A02_S	12.23	13.45	1.22		12.62	11.58	1.03	
A03_L	9.54	12.47	2.92	0.87	12.50	12.47	0.03	0.11
A03_S	8.55	10.60	2.05		10.78	10.92	0.14	
A04_L	7.66	13.45	5.79	0.35	8.80	8.28	0.53	0.18
A04_S	6.85	12.29	5.44		8.85	8.50	0.35	
A05_L	8.95	14.36	5.41	0.80	11.63	13.61	1.98	1.08
A05_S	10.59	15.20	4.61		11.30	10.40	0.90	

Largest peak torque per helmet fit
Largest peak torque per subject
Largest peak torque per helmet fit
Largest peak torque per subject

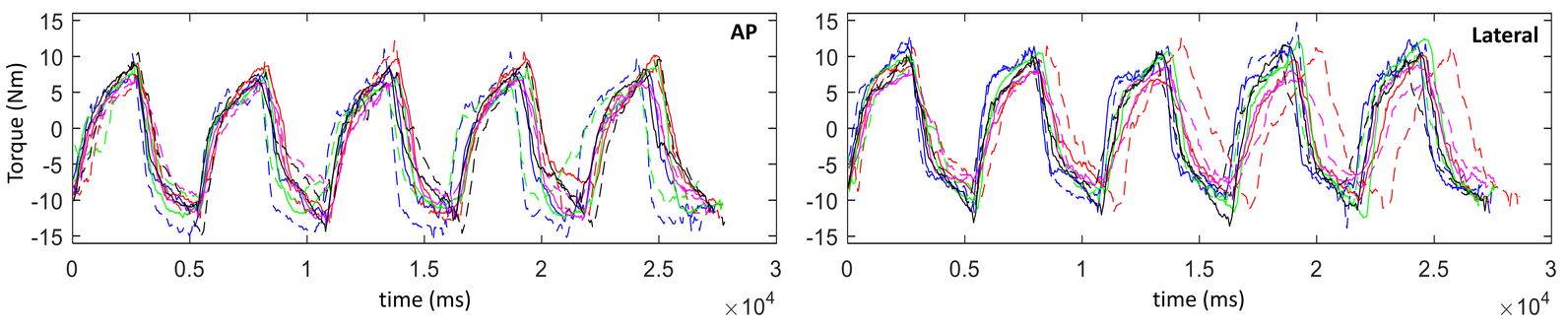

Figure 3: Torque comparisons between all subjects with both helmet fits at 30°/s. Left: AP direction. Right: Lateral direction. Solid lines: Loose fit; Dashed lines: Snug fit. Blue: A01; Red: A02; Green; A03; Magenta: A04; Black: A05.

DISCUSSION & CONCLUSIONS

- There were no patterns between peak torque generation and helmet fit.
  - AP direction: all maximum peak torques occurred in extension.
  - Lateral direction: maximum peak torques occurred more frequently towards the subjects' right.
- Comparing measured peak torques to the literature, we found that our protocol results in comparable torque calculations of the atlantooccipital junction.[6]
- Helmet fit does not affect subjects' ability to engage with the equipment nor to produce maximum torque during the 30°/s portion of the protocol in both directions.
- The custom head fixture produces consistent and repeatable data outputs.
- Next steps include testing pediatric volunteers 5–7 years old, to better understand the unique characteristics of the pediatric c-spine.
- With these new data, we will help bridge the gap of knowledge in the pediatric biomechanics field and begin to improve the biofidelity of the current pediatric HBMs and ATDs.

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