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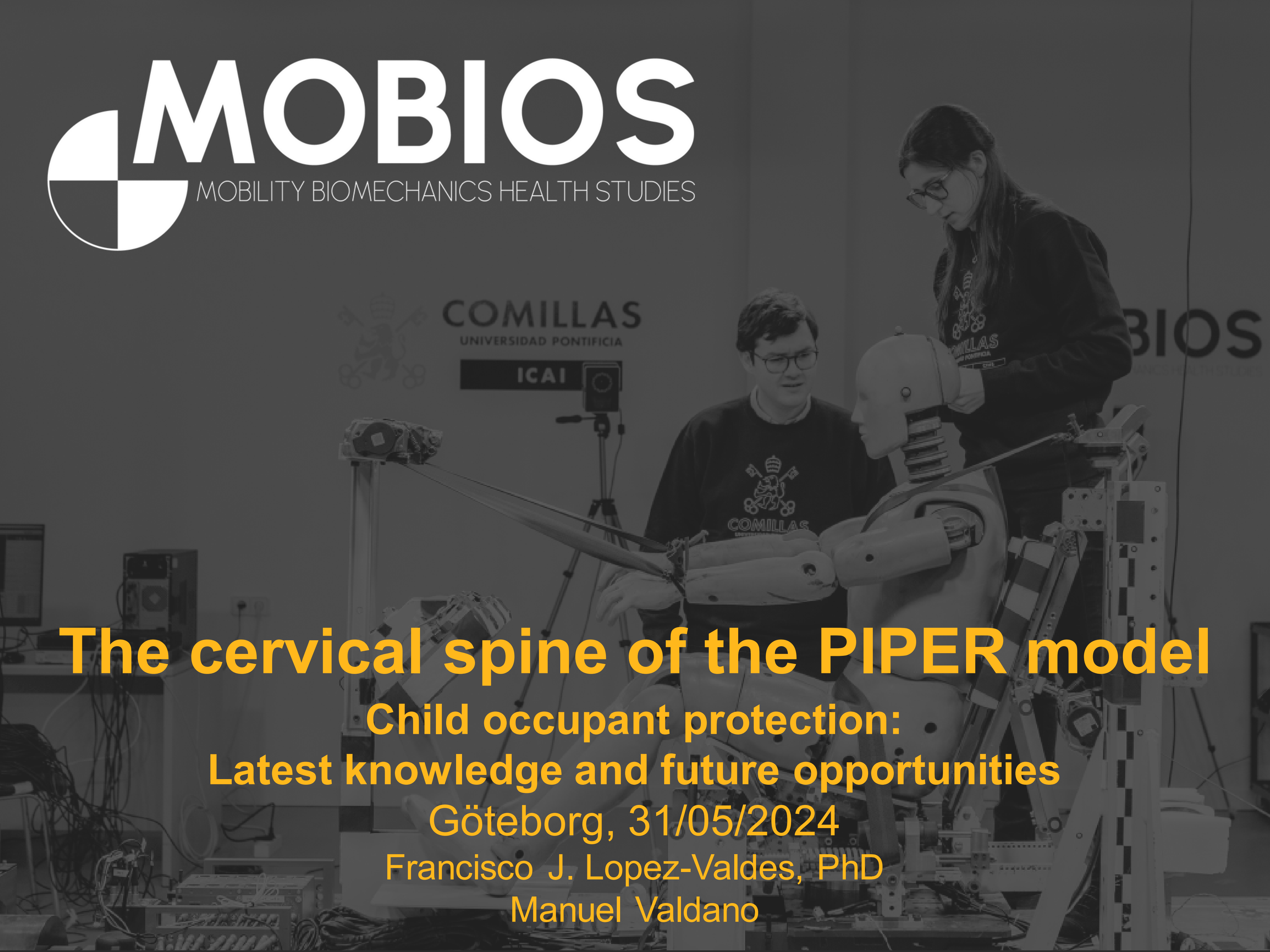
MOBILITY BIOMECHANICS HEALTH STUDIES



The cervical spine of the PIPER model

Child occupant protection:
Latest knowledge and future opportunities

Göteborg, 31/05/2024

Francisco J. Lopez-Valdes, PhD
Manuel Valdano

UNECE R129

E/ECE/324/Rev.2/Add.128/Rev.4
E/ECE/TRANS/505/Rev.2/Add.128/Rev.4

6.6.4.3.1. Injury assessment criteria for frontal and rear impact as in Table 4.

Table 4

Criterion	*Abbreviation*	*Unit*	*Q0*	*Q1*	*Q1.5*	*Q3*	*Q6*	*Q10*
Head performance criterion (only in case of contact during in-vehicle testing)	HPC* (15)		600	600	600	800	800	800
Head acceleration 3 ms	A head Cum3 ms ***	g	75	75	75	80	80	80
Upper neck tension Force	Fz	N	For monitoring purpose only**					
Upper neck flexion moment	My	Nm						
Chest acceleration 3 ms	A chest Cum 3 ms ***	g	55	55	55	55	55	55
Chest deflection	TBC	mm	NA	For monitoring purpose only**				
Abdominal pressure****	P	Bar	NA	NA	1.2	1.0	1.0	1.2

* HPC: see Annex 17.
** To be reviewed within 3 years following entry into force of the series 01 of this Regulation.

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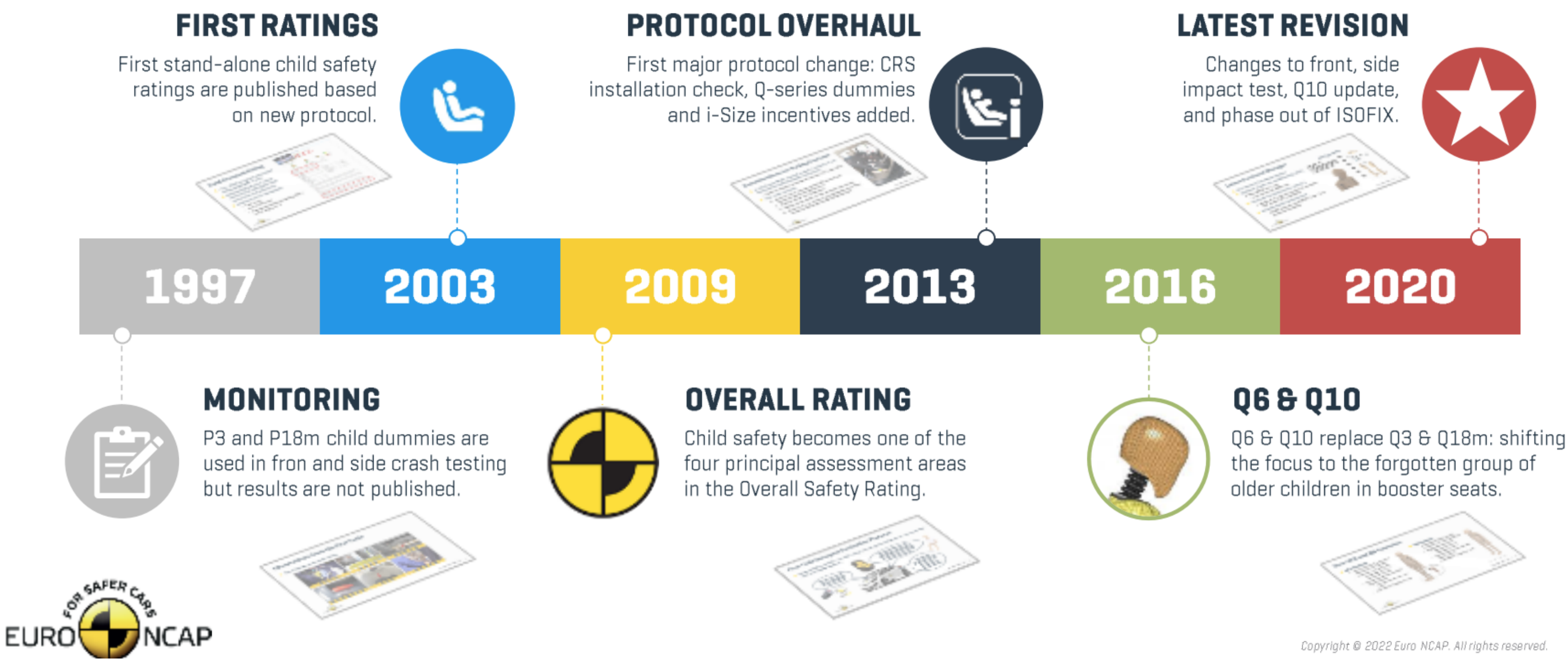
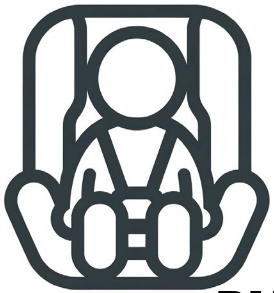
EuroNCAP

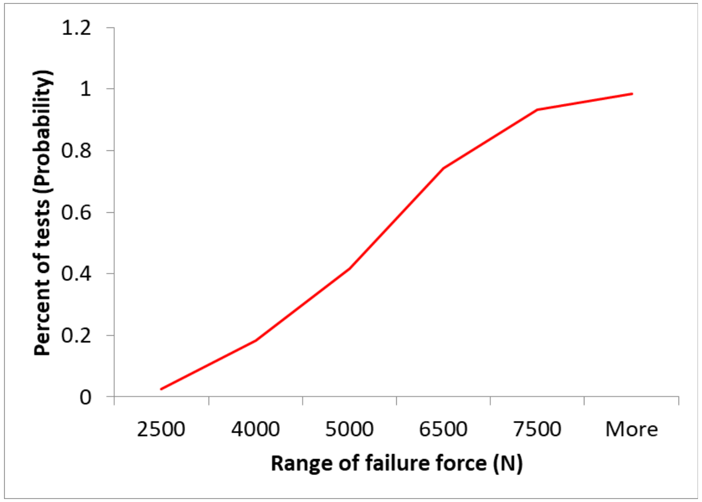


EuroNCAP proposes a 1.7-2.6 kN (Q6) for neck tension but…
child dummies may have **biofidelity issues** and
a lack of injury criteria and thresholds

How injury criteria are created?




PMHS
(Post Mortem Human Subjects)
experiments

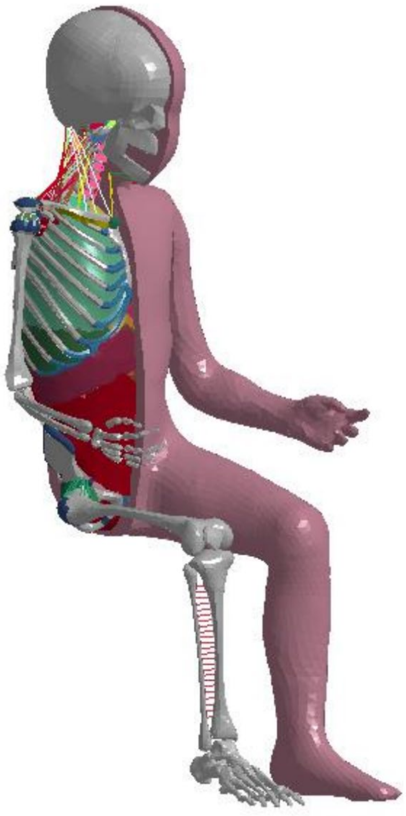



How injury criteria are created?

Only **15 pediatric PMHS** have been ever performed and most of them in the 1970s, with **restraint systems and instrumentation very different** from what is relevant today

The PIPER pediatric HBM

- Presented in 2015, EU funded project
- **<u>Scalable</u>** child HBM: 18 months to 6YO and older
- Baseline: 6 YO, anthropometry based on GEBOD regressions, 23 kg, 1146 mm
    - Skin and external shape based on UMTRI models
    - 353 parts, 531,000 elements
- Integrated with the PIPER positioning tool
- Freely available, **<u>modifications need to be shared publicly</u>** under the current license
- Defined sensors to compare readings with Q-dummy outputs



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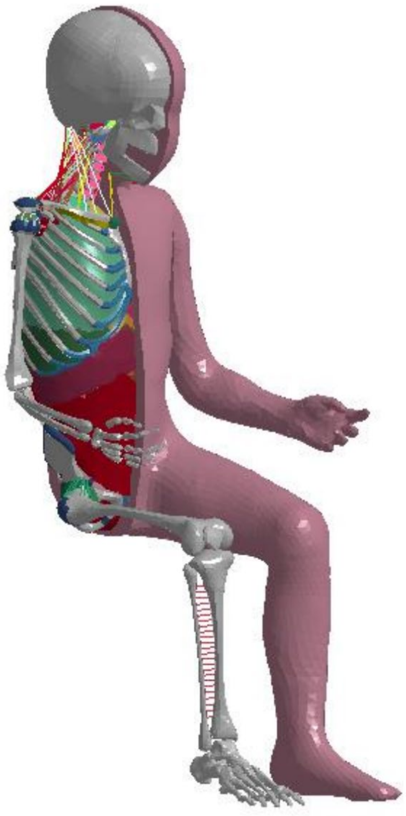
The PIPER pediatric HBM

Set	Published Study	ROI	Dir	Impactor/loading	Subjects and ages		Target model and version	
1	Loyd (2011)	Head		Drop test (dyn)	PMHS	9	6	0.3
	Loyd (2011)	Head		Compression (dyn)	PMHS	9	6	0.3
	Ouyang et al. (2005)	Neck		Bending+tensile	PMHS	6	6	0.3
	Ouyang et al. (2005)	Neck		Bending+tensile	PMHS	3	3	0.3
	EEVC Q (2008)	Shoulder	Side	Pendulum, free back (dyn) Scaled	PMHS	Adult	6	0.202
	Ouyang et al (2006)	Thorax	Frontal	Pendulum, free back (dyn)	PMHS	6+	6	0.202
	Kent et al (2011)	Thorax	Frontal	Belt distributed, fixed back (dyn)	PMHS	6 & 7	6	0.202
	Kent et al (2011)	Thorax	Frontal	Belt diagonal, fixed back (dyn)	PMHS	6 & 7	6	0.202
	EEVC Q (2008)	Abdo	Frontal	Belt, fixed back Scaled corr.	Porcine	6	6	0.202
	Kent et al (2011)	Abdo	Frontal	Belt mid abdo, fixed back (dyn)	PMHS	6 & 7	6	0.202
	Kent et al (2011)	Abdo	Frontal	Belt upper abdo, fixed back	PMHS	6 & 7	6	0.202
	Part 572	Lumbar	Frontal	Torso flexion (static)	HIII	6	6	0.202
	Ouyang et al (2003a)	Pelvis	Side	Pendulum, free back (dyn)	PMHS	various	6	0.202
	Ouyang et al. (2003b)	Femur		Bending test	PMHS			0.301
	Wismans et al (1979)	WB neck	Frontal	Sled test, harness (4 YO anthro)	PMHS	6	6	0.3
	Kallieris et al (1976)	WB	Frontal	Sled test with shield	PMHS	2.5, 6		*
	Lopez et al (2011)	WB spine	Frontal	Sled test with belt (dyn)	Volunteer		6	*
	Arbogast et al (2009)	WB neck	Frontal	Sled test, 3pt belt	Volunteer	6+	6	*



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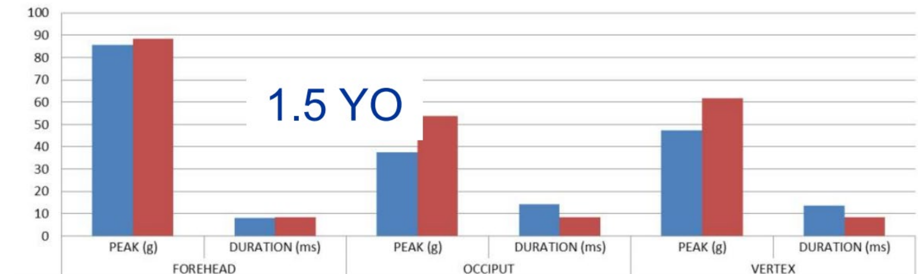
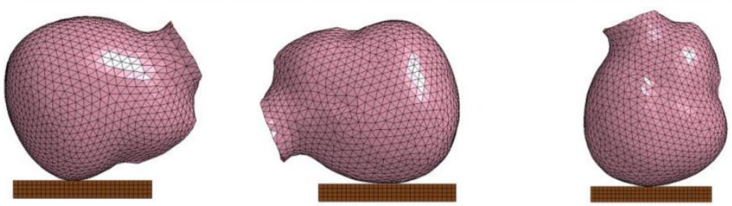
The PIPER pediatric HBM

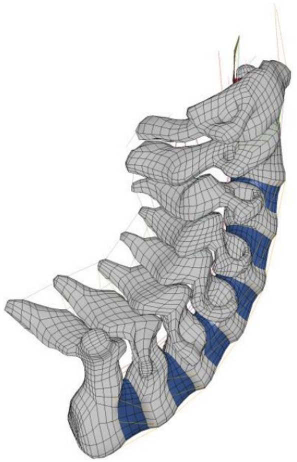
Head impacts (Lloyd, 2011)

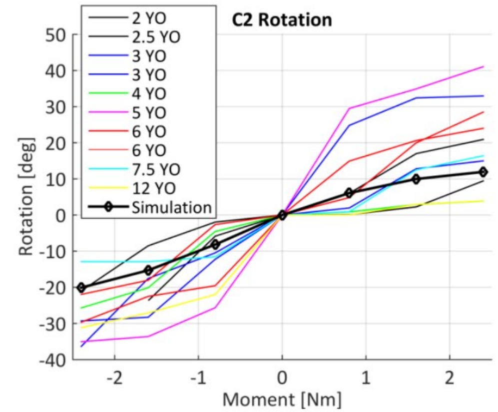


	FOREHEAD PEAK (g)	FOREHEAD DURATION (ms)	OCCIPUT PEAK (g)	OCCIPUT DURATION (ms)	VERTEX PEAK (g)	VERTEX DURATION (ms)
Exp	85,6	8,2	37,6	14,2	47,2	13,6
Model	88,3	8,5	53,85	8,5	61,8	8,5



Cervical flexion (Ouyang et al, 2005)





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Ouyang et al. 2005

SPINE Volume 30, Number 24, pp E716–E723

Biomechanical Assessment of the Pediatric Cervical Spine Under Bending and Tensile Loading

Jun Ouyang, PhD,* Qingan Zhu, PhD,* Weidong Zhao, BS,* Yongqing Xu, PhD,†
Weisheng Chen, MS,‡ and Shizhen Zhong, MD*

Test	Subject	Age (yr)	Sex	Weight (kg)	Stature (cm)	Cause of Death
ECad1	Child0	~5	M	13	91.3	Unknown
CCad1	Child1	12	F	29	142.5	Leukemia
CCad2	Child3	3	F	10.5	85.0	Heart disease
CCad3	Child11	6	M	20	109.0	Mediterranean edema
CCad4	Child4	2	F	13	97.0	Fluoracetamide poisoning
CCad5	Child5	2.5	M	10.5	87.5	Cerebral edema
Ccad6	Child6	3	M	13.5	93.0	Brain tumor
Ccad7	Child2	7.5	F	17	117.0	Acute urinaemia
Ccad8	Child10	6	M	16.5	108.0	Leukemia
Ccad9	Child9	5	M	13	101.0	Cerebritis
Ccad10	Child7	3	M	10	91.0	Congenital heart disease
Ccad11	Child8	4	M	14	109.0	Congenital heart disease
Ccad12	Child12	12	F	20	140.0	Congenital heart disease

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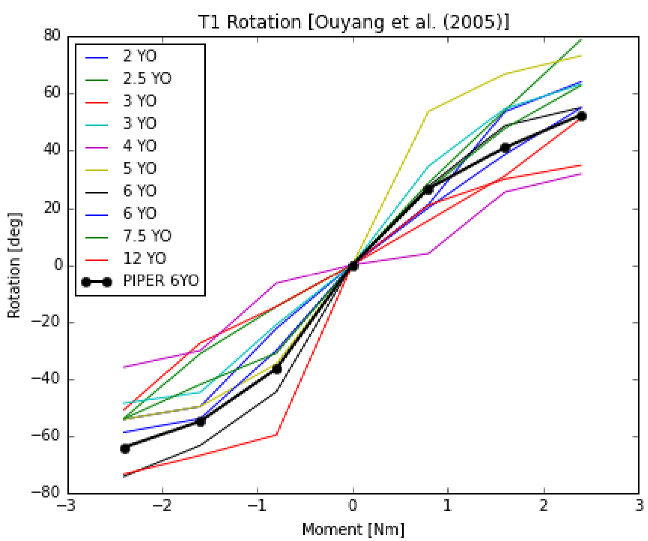
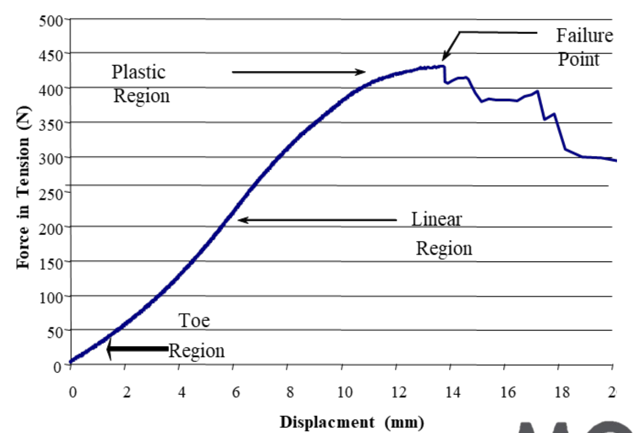
Ouyang et al. 2005: 2 types of tests

Bending tests
(non-injurious):
Moment (Nm)
vs.
Rotation (deg)

Tensile tests
(injurious):
Force (N)
vs.
Displacement (mm)

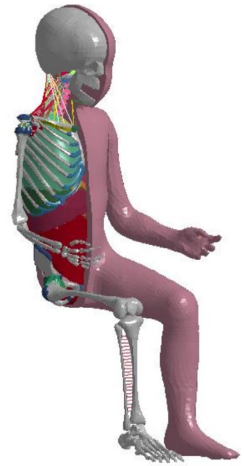




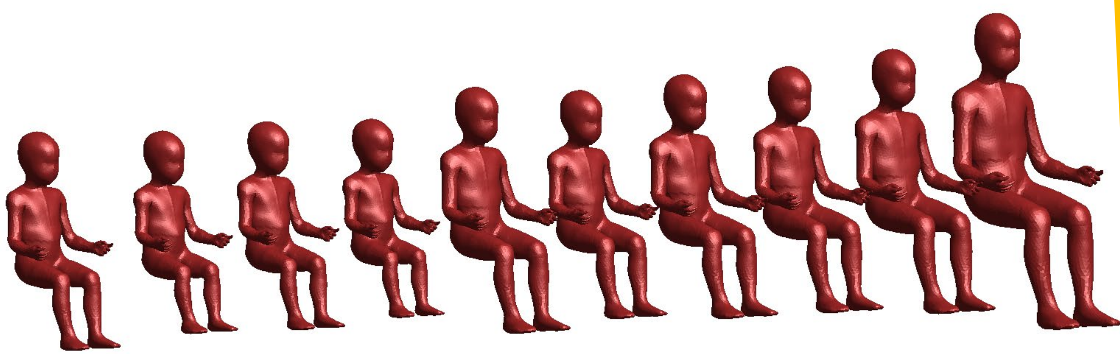
Goal

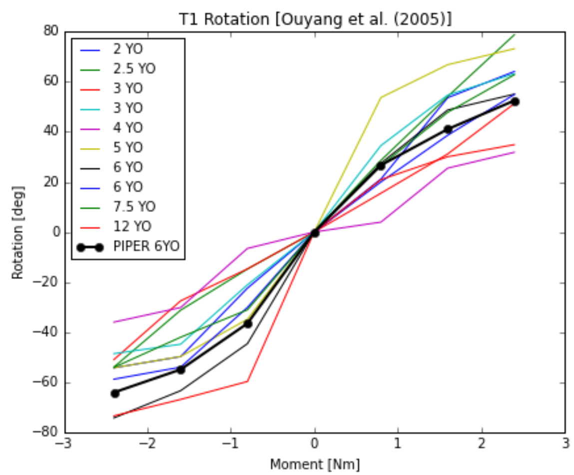
Can the PIPER model be updated so that its mechanical response reflects more accurately the response of each of the pediatric PMHS?

Method



Use the PIPER scaling tool to scale the PIPER model to the anthropometry of the pediatric PMHS





Compare response of scaled PIPER to original pediatric PMHS

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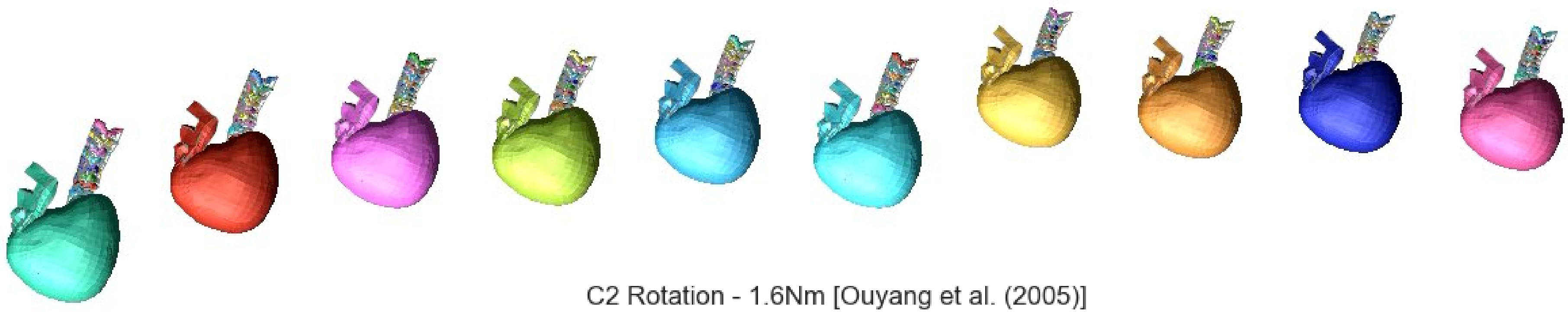
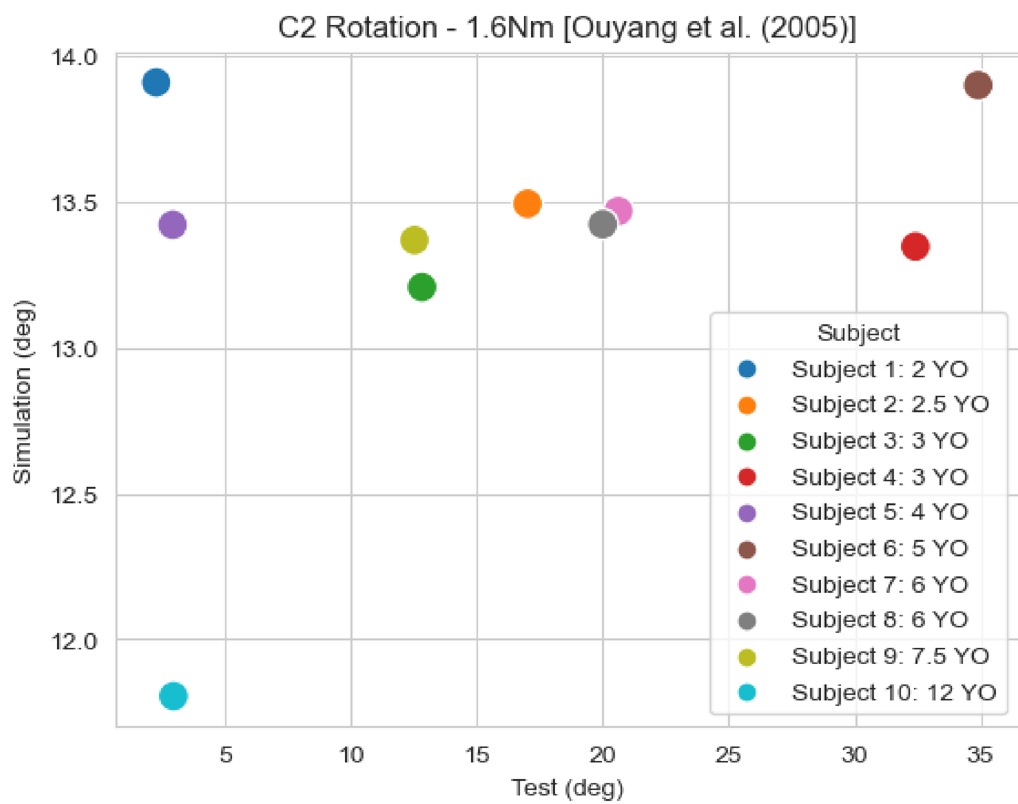
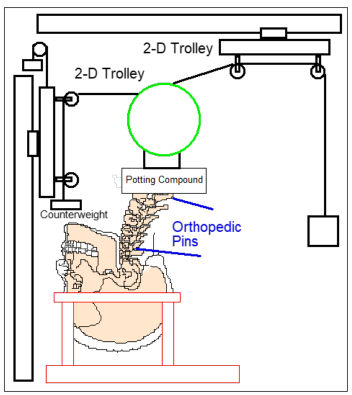
Results



Variability in simulation





Variability in experiments

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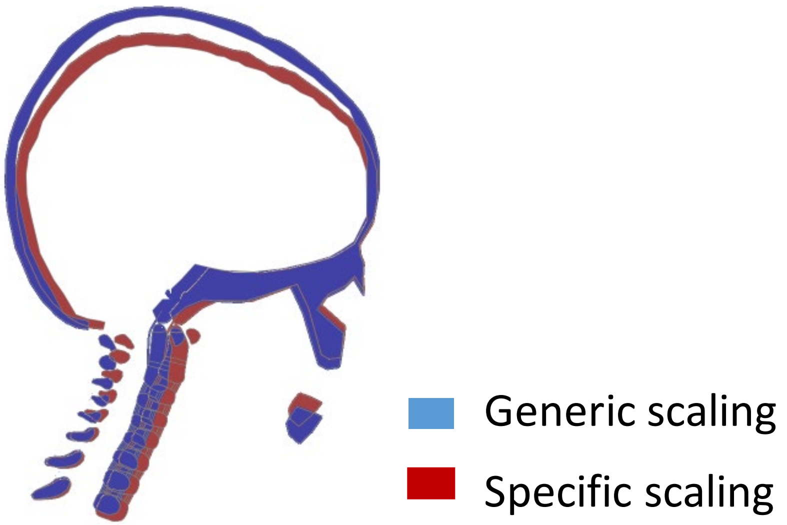
Goal

Can the PIPER model be updated so that its mechanical response reflects more accurately the response of each of the pediatric PMHS?

Perhaps, a more detailed scaling of the anthropometry of the pediatric PMHS can improve the result?



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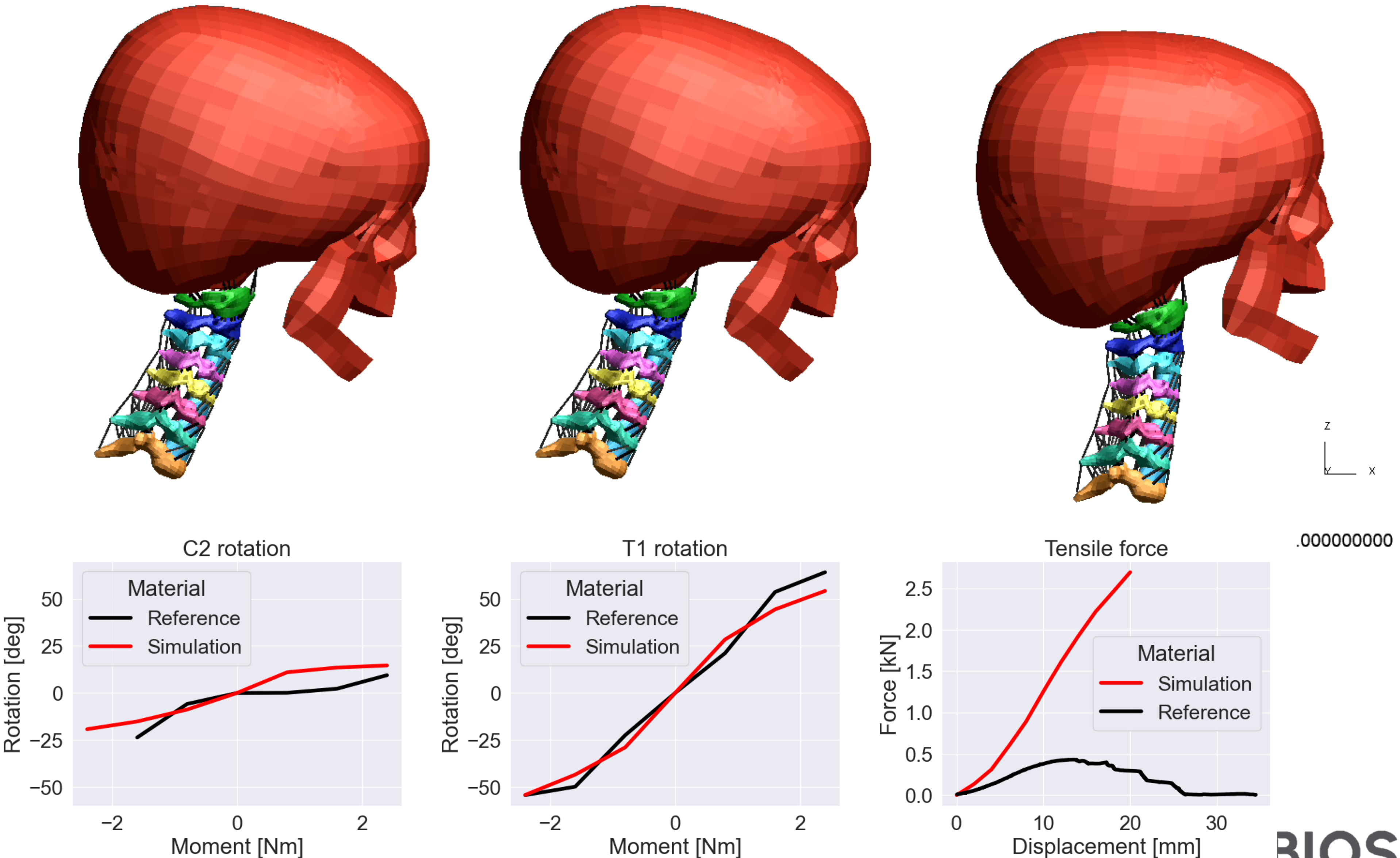
Results



z
x
.000000000
C2 rotation
Material
Reference
Simulation
Rotation [deg]
Moment [Nm]
T1 rotation
Material
Reference
Simulation
Rotation [deg]
Moment [Nm]
Tensile force
Material
Simulation
Reference
Force [kN]
Displacement [mm]

Goal

Can the PIPER model be updated so that its mechanical response reflects more accurately the response of each of the pediatric PMHS?

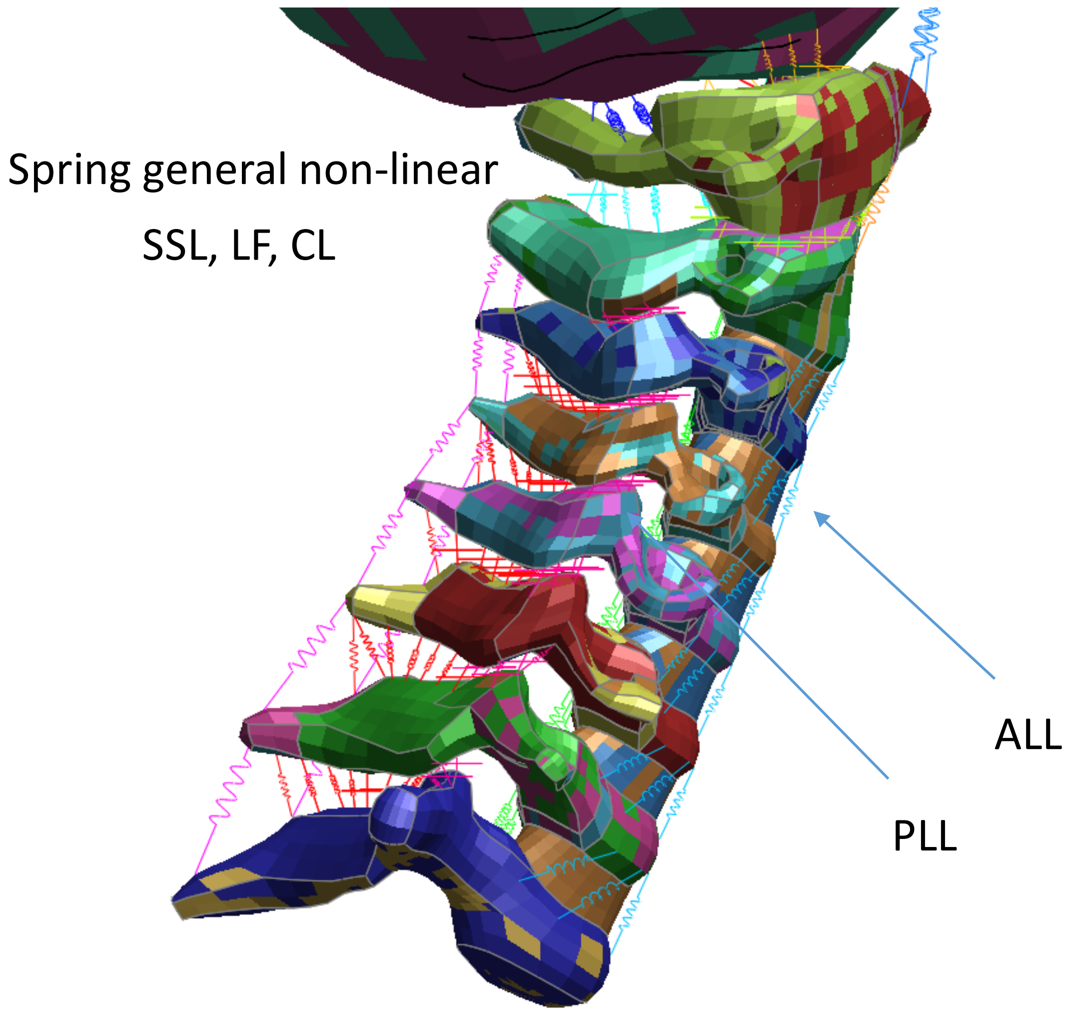
Perhaps, a more detailed scaling of the anthropometry of the pediatric PMHS can improve the result?

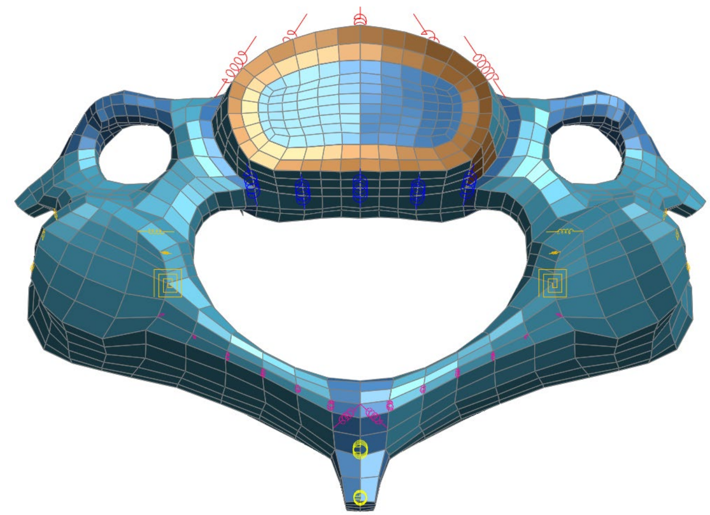
Perhaps, we can find a better description of the mechanical properties of the tissues of the cervical spine that improve the response of the model?

Methods

Intervertebral disc:

- Nucleos pulposus (3D), Mooney-Rivlin
- Annulus fibrosus (2D), Fabric
- Ground substance (3D), General viscoelastic



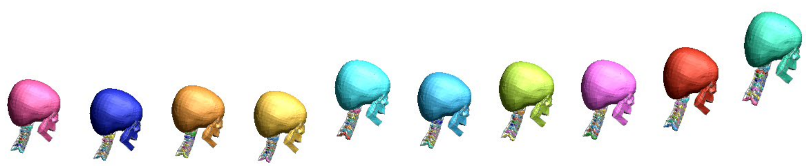


Methods

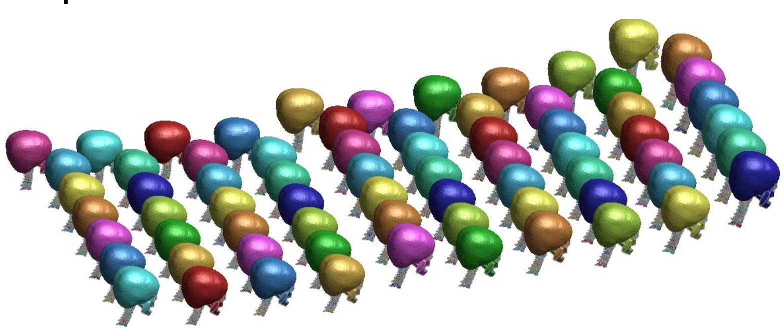
Parameter	Description
K_L	Scaling of ligament response
K_N	Scaling of nucleus pulposus response

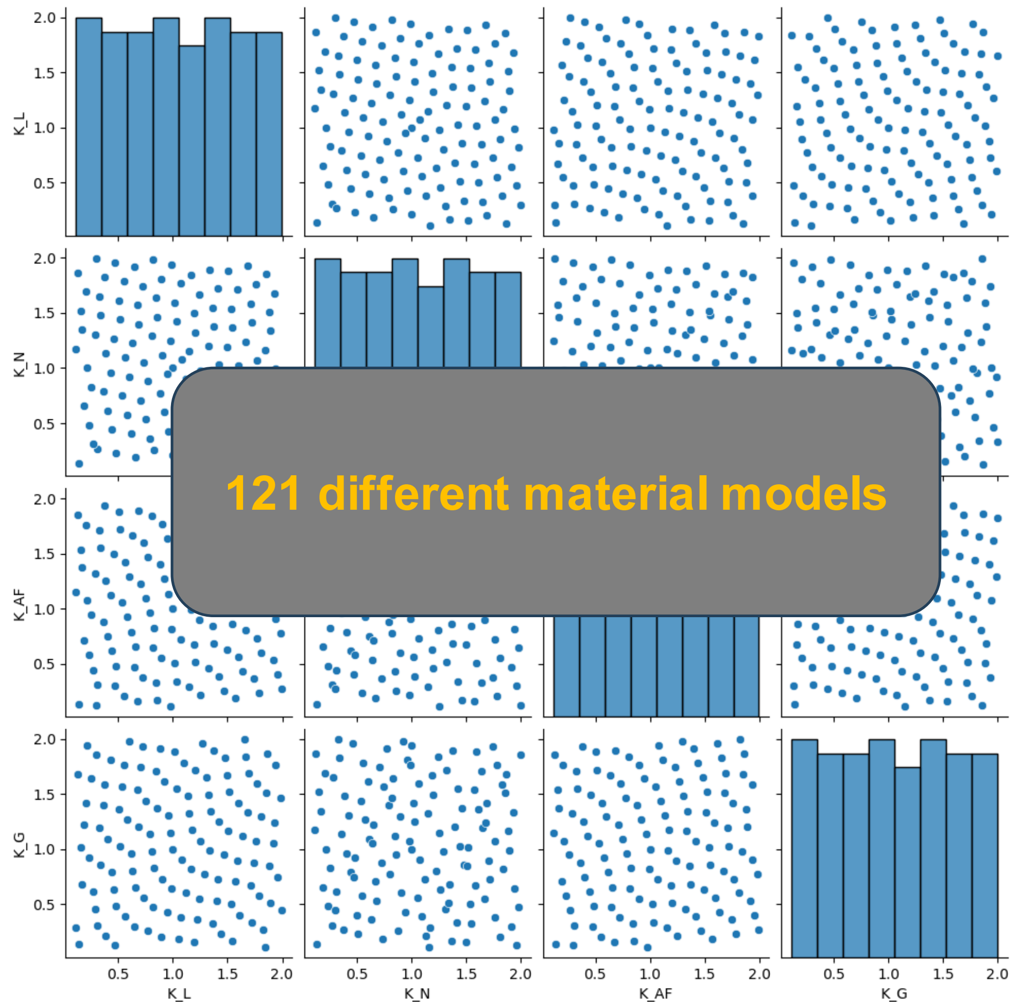
Not optimizing the material properties for one subject…

But finding a relationship that could account for how these material properties evolve with age…



For both the bending and tensile experiments at the same time





121 different material models

19	Ligamentum flava	K_L
20	Supraspinous ligament and Interspinous Ligament	K_L

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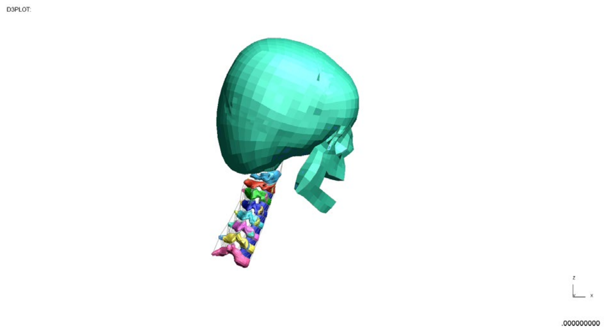
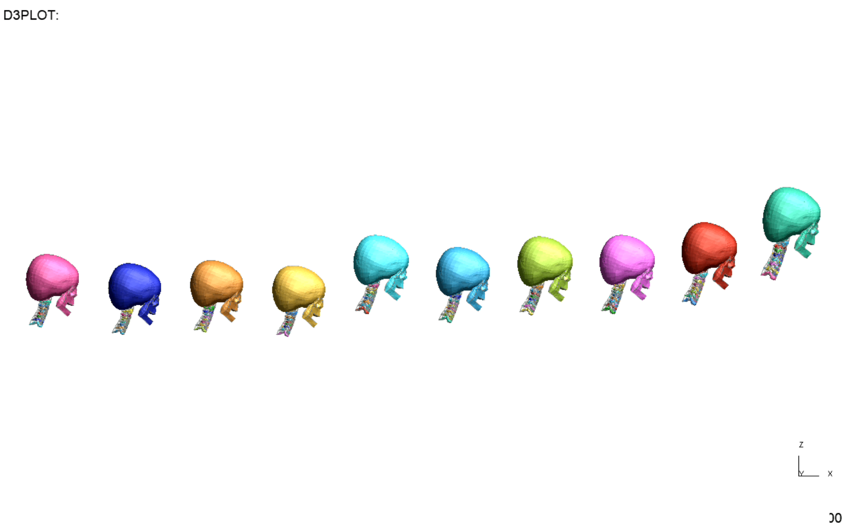
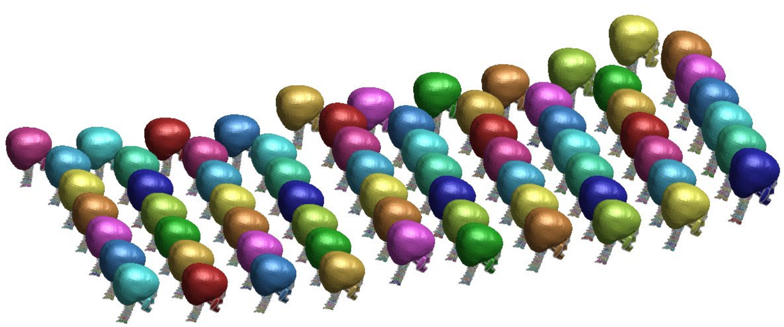
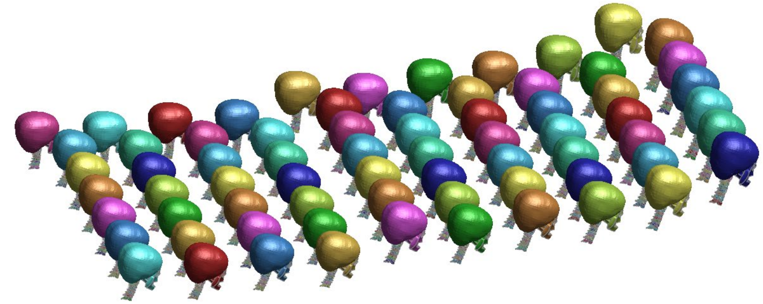
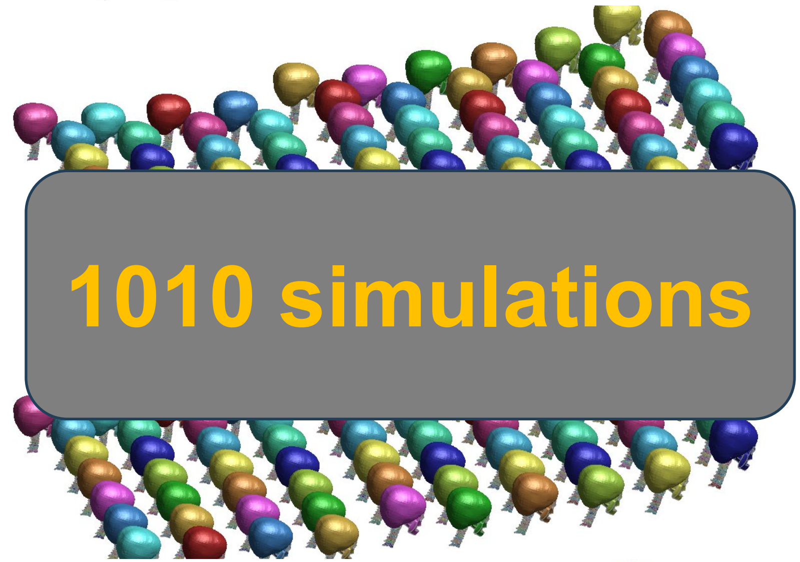
Methods



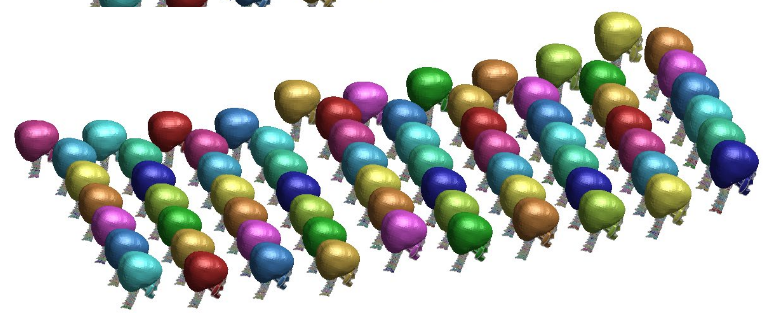








1010 simulations



Goal

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Perhaps, a more detailed scaling of the anthropometry of the pediatric PMHS can improve the result?

Perhaps, we can find a better description of the mechanical properties of the tissues of the cervical spine that improve the response of the model?

Shall we try other material models for the components of the cervical spine?

Summary

- The current PIPER neck model is optimized to represent rotation within the physiological range, but it is too stiff to represent correctly tensile forces (Fz).

- The material models used to described the behavior of the cervical structures can be modified to improve its response under tensile forces.

- This work is still ongoing, but **preliminary results** are encouraging.

Acknowledgment

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Inglesina

Baby Wellness FOUNDATION

Ministero dello sviluppo economico