Helmet loads on the cervical spine in non-neutral postures across the anthropometric spectrum: a finite element analysis

Dr. Zachary J Domire

East Carolina University, Department of Kinesiology, Performance Optimization Lab

Acknowledgements

- I would like to thank my co-authors Dr. Mackenzie Hoey Dr. Constantin Heinemann, and Dr. Alex Vadati

- This work was supported by Office of Naval Research (N000142112649).

Disclosure

- This material is based upon work while co-author Alex Vadati worked at the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or of the Federal government.
- Dr. Hoey, Dr. Heinemann, and Dr. Domire have nothing to disclose.

Background

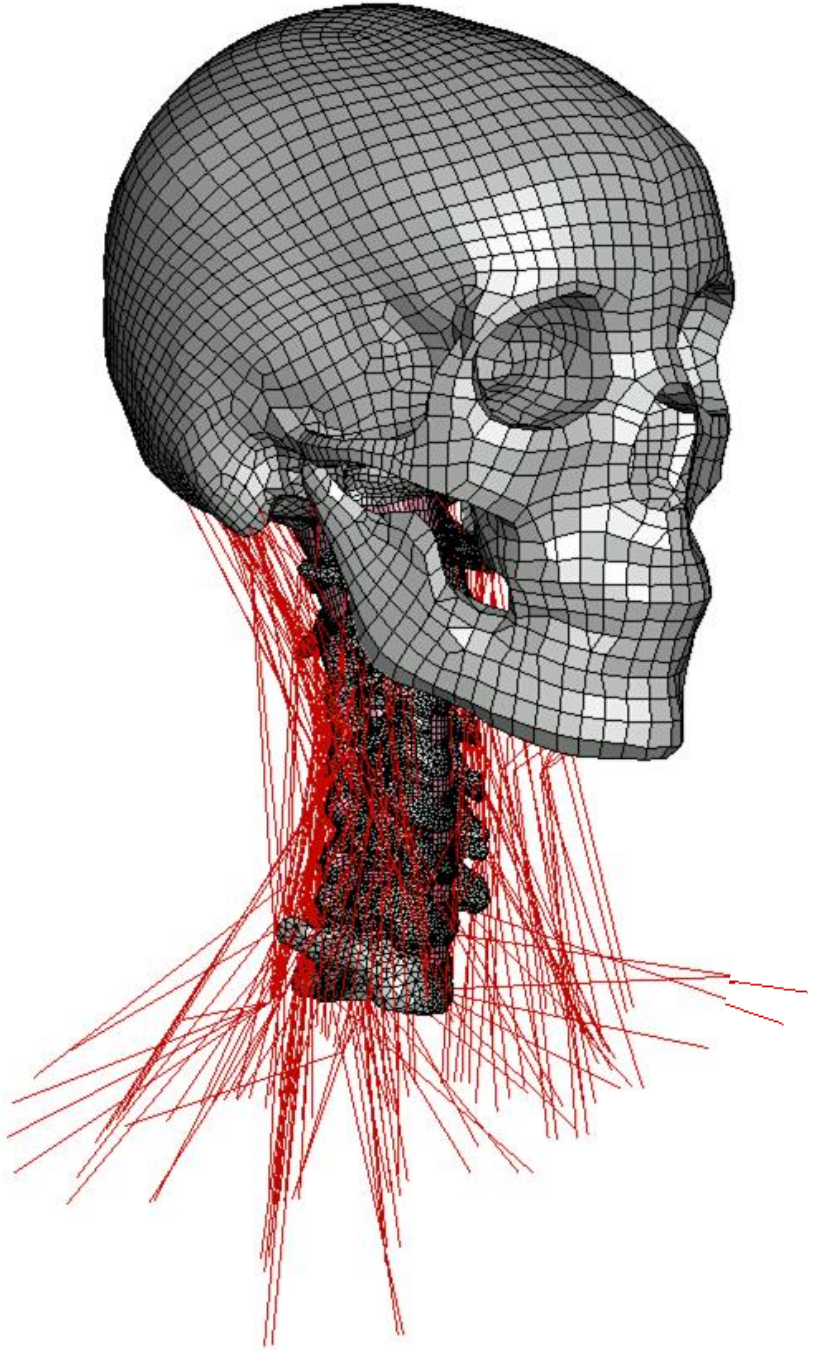
- 97% of fighter pilots experience neck pain
- Pain has been correlated to helmet loads
- Pain interferes with flying and causes sick leave
  - Training a single pilot costs up to $10.9 million
- Non-neutral postures are high-risk movements for injuries
  - Flexion greater than 15°
  - Axial rotation greater than 35°
  - Checking six
- Neck pain severity varies across pilot size
  - 1st and 2nd quartile leg length report most severe neck pain

Potential pain mechanisms

- Overstrained muscles
  - Strength training interventions have proven to be ineffective
- Intervertebral disc (IVD) pressure (>1.0 MPa) and stress (>3.6 MPa)
  - Pilots show elevated rates of disc degeneration
- Facet joint loading
  - Studies suggest that 39-67% of neck pain originates in the facet joints
- Nerve root (NR) pressure (>6.7 kPa or >13.3 kPa)
  - Symptoms reported by pilots are consistent with NR compression
  - Narrowing of the foraminal space in axial rotation generates pathological pressures on NRs

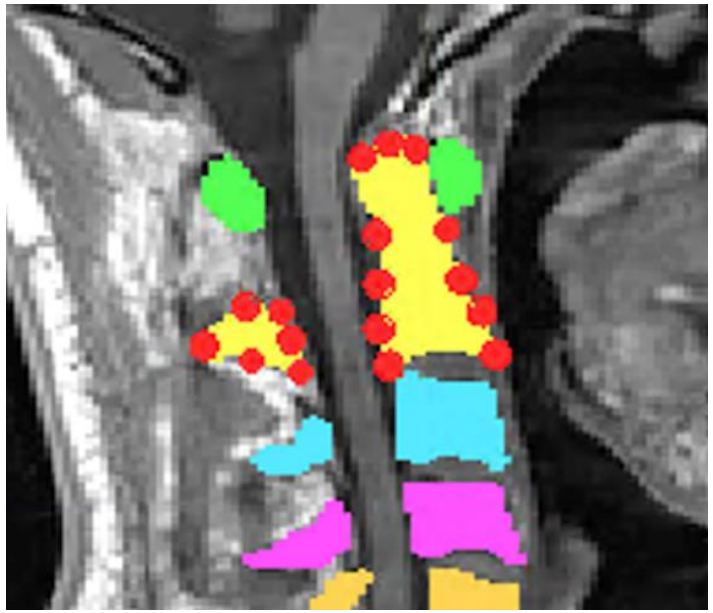
Finite element analysis

- Studying the effects of helmet loads *in-vivo* is difficult and leads to ethical complications
- Finite element analysis (FEA) may be utilized to predict what happens to NRs under helmet loads
  - In FEA, a 3D model of the neck is created and broken down into small pieces
  - Each piece is assigned a set of equations that determines how it responds to load and how it interacts with other tissues in the model

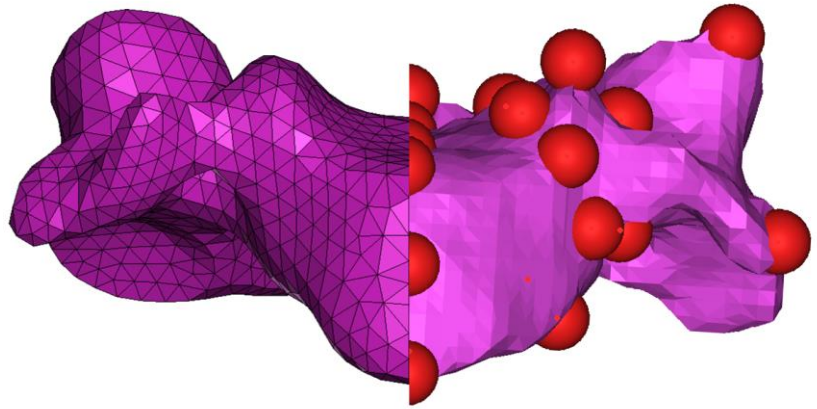


Methods – model morphing

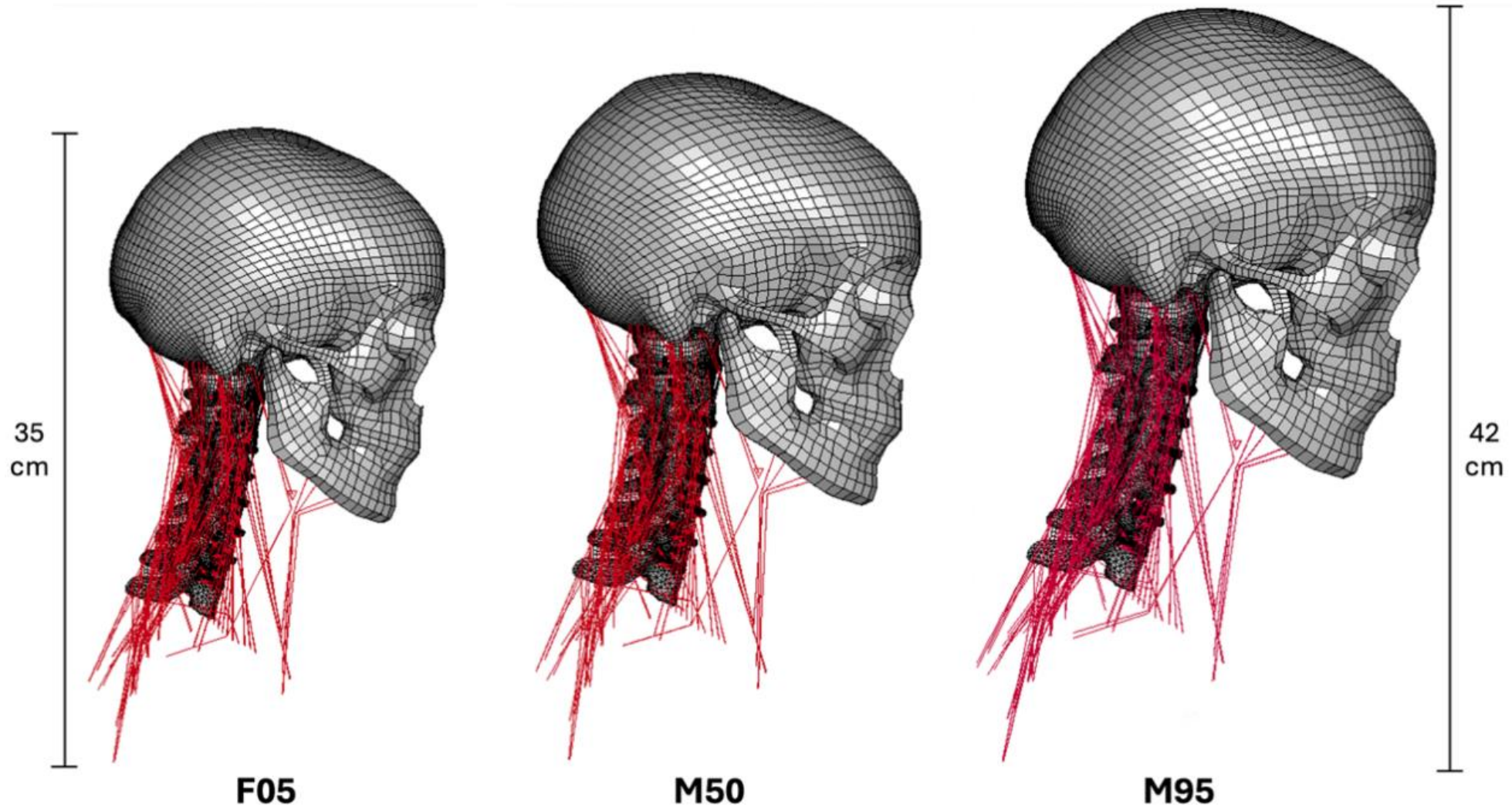
- 3 participants identified for MRIs by neck circumference
  - 5th percentile female (F05)
  - 50th percentile male (M50)
  - 95th percentile male (M95)
- Anatomical landmarks identified on MRIs
- Dual-kriging interpolation positioned remaining nodes
- Subject-specific muscle CSAs from MRIs
- Head inertial properties altered



	Participant	Army report
F05	29.5 cm	29.2 cm
M50	37.8 cm	37.9 cm
M95	43.9 cm	41.3 cm

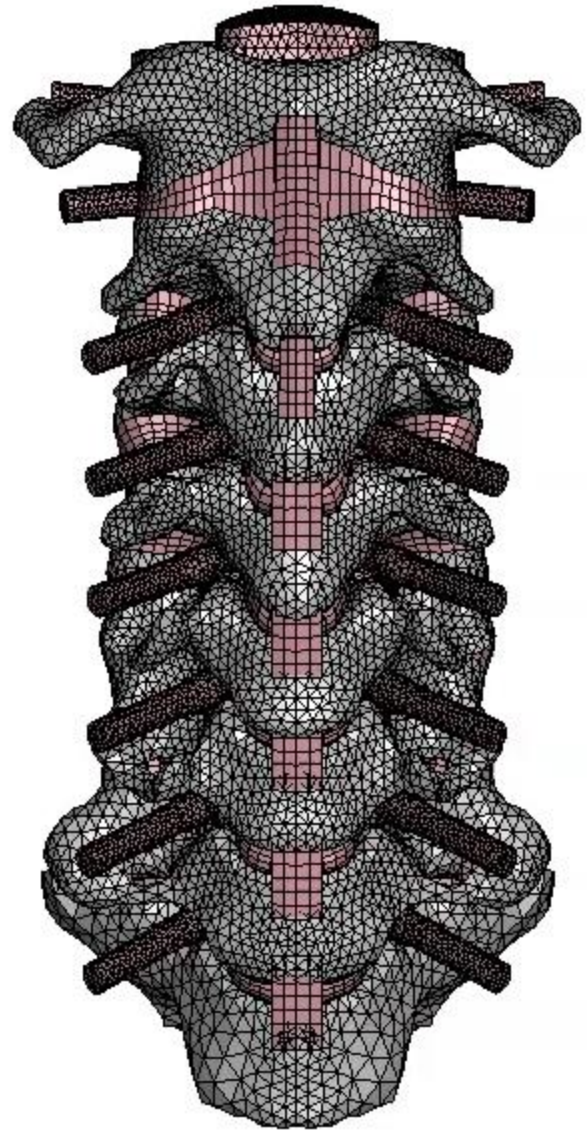


Final models

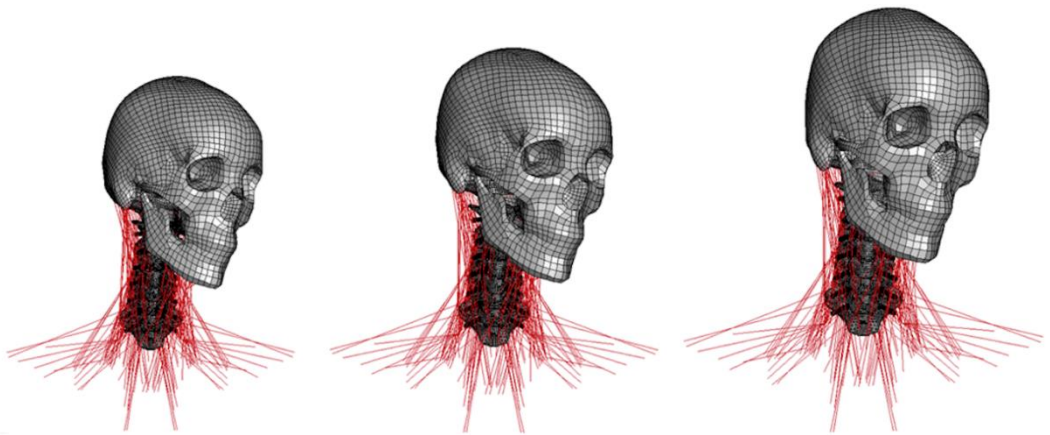


Methods – model rotation

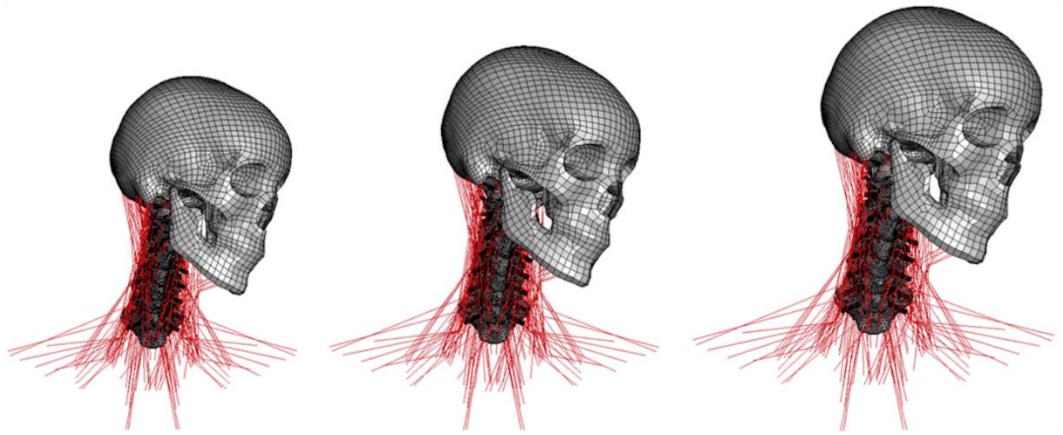
- Local coordinate systems were defined at each vertebrae to rotate models into:
  - Flexion
  - Axial rotation
  - Check six
- Boundary conditions:
  - Helmet/no helmet load
  - Gravity
  - PID + SWE muscle forces
  - Fixed T1
- Muscle activation, IVD degeneration, facet loads, and NR compression analyzed



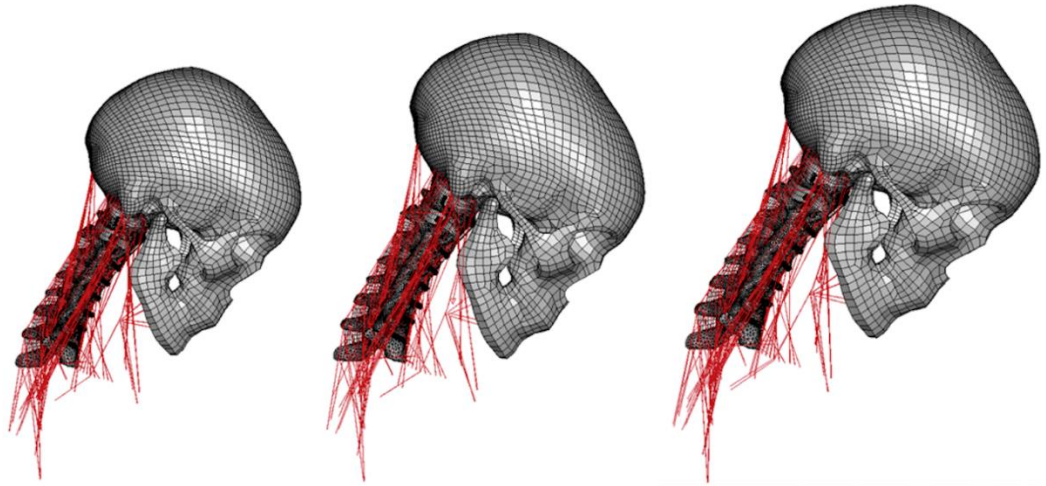
Rotated models



Axial Rotation



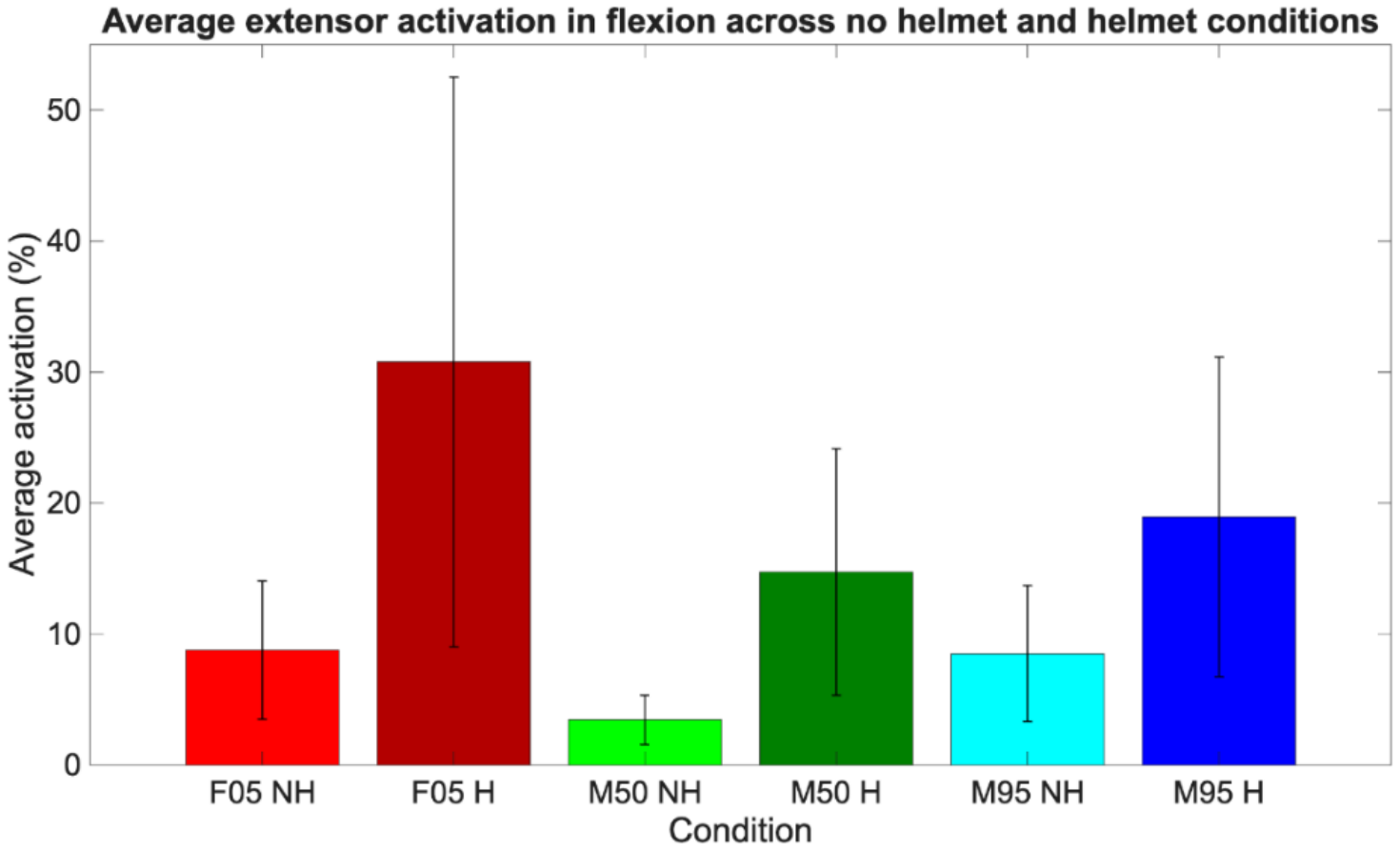
Check six



Flexion

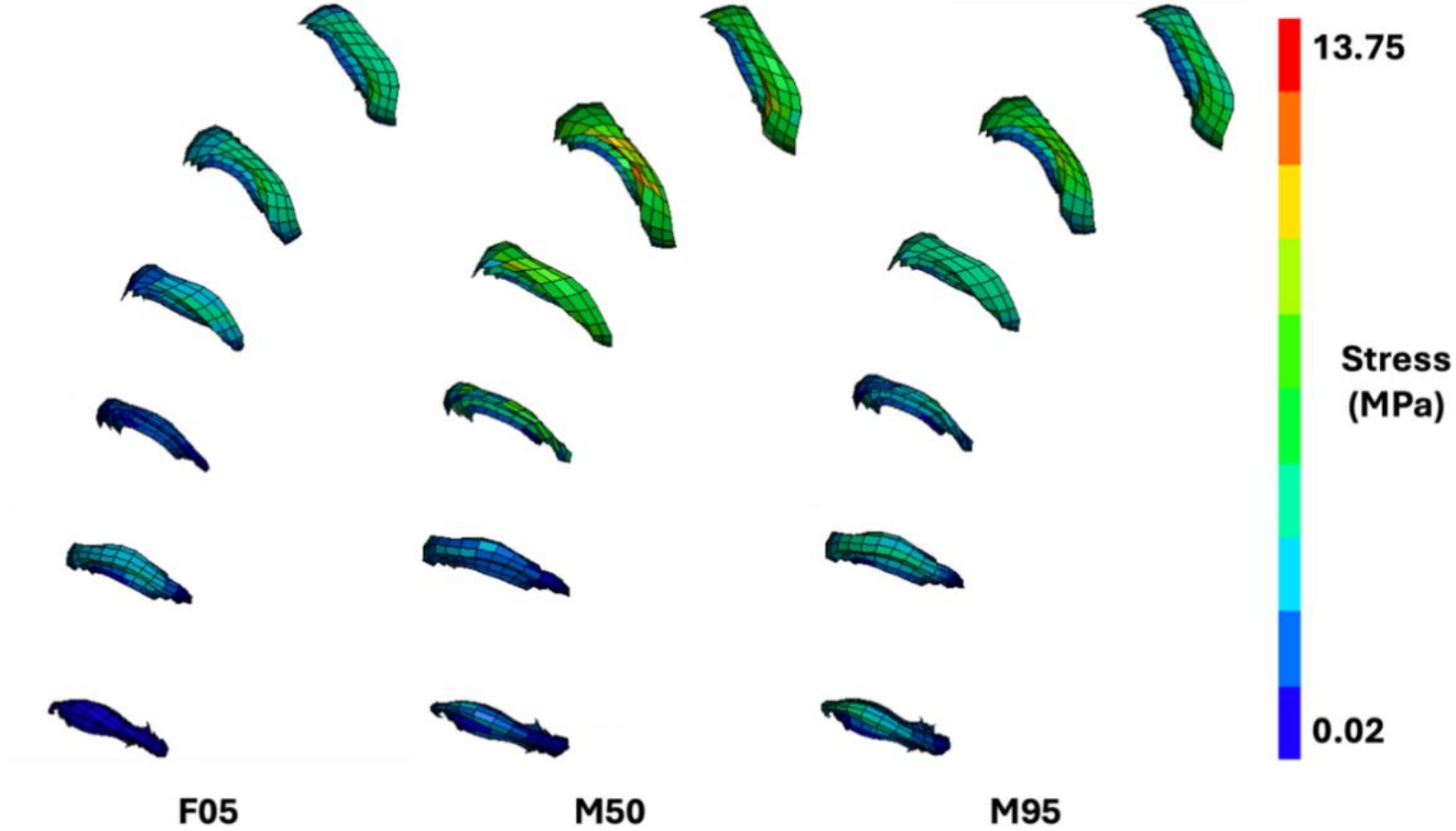
Flexion - Extensor activation

- F05 displayed the largest average extensor activation to maintain a flexion posture under helmet loads



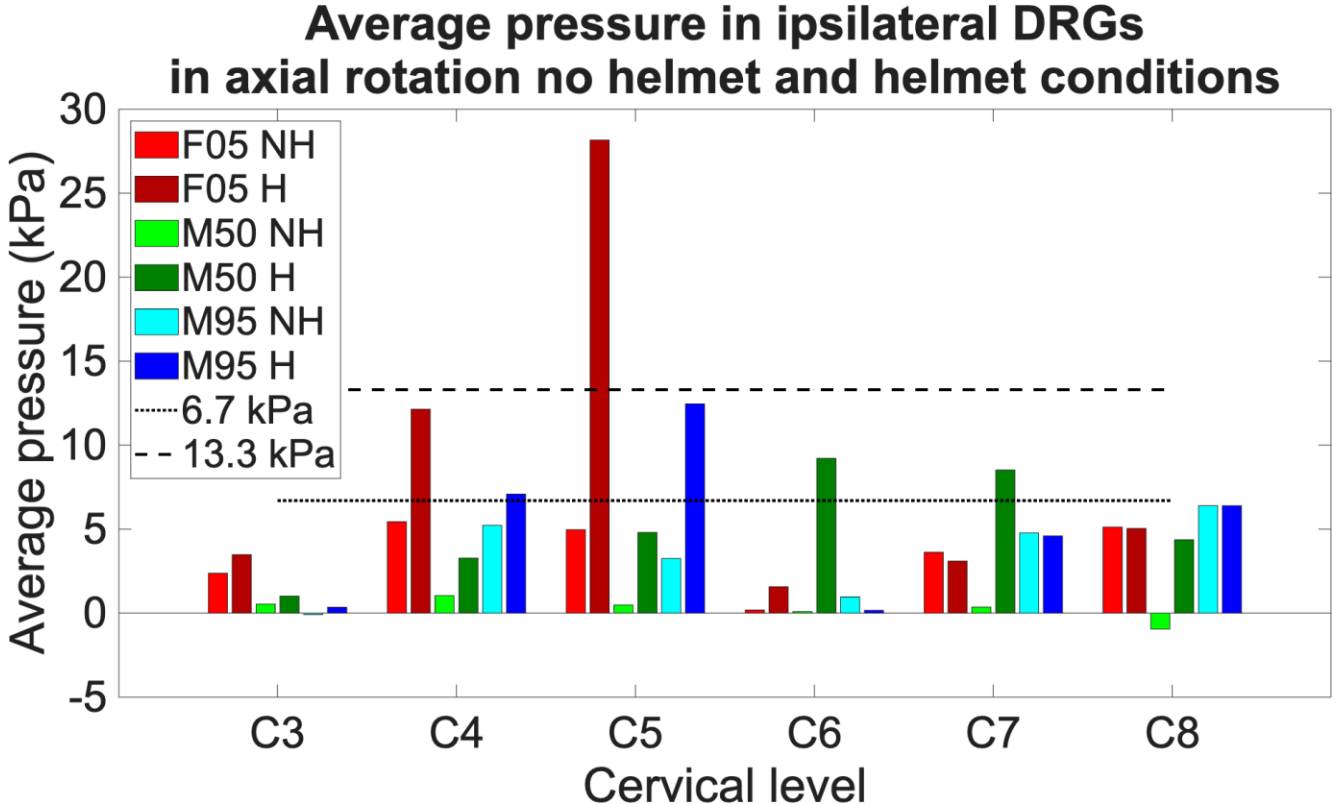
Flexion - IVD fiber stress

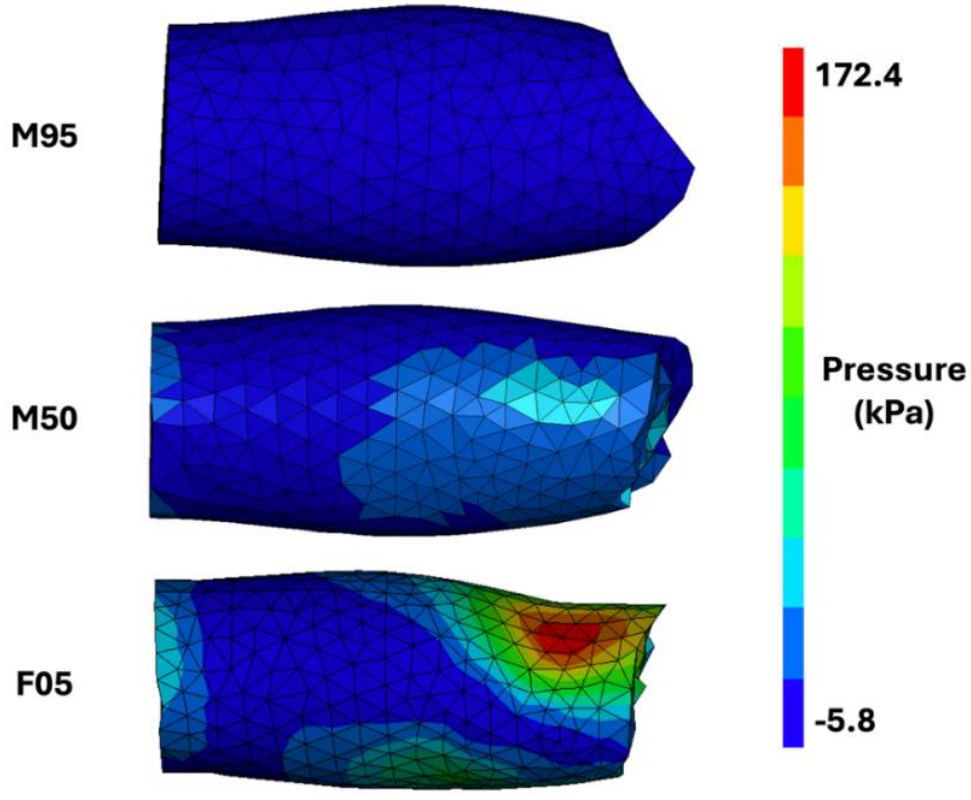
- The M50 and M95 models showed damaged IVD fibers in flexion under helmet loads (>3.6 MPa)



Axial rotation - Nerve root pressure

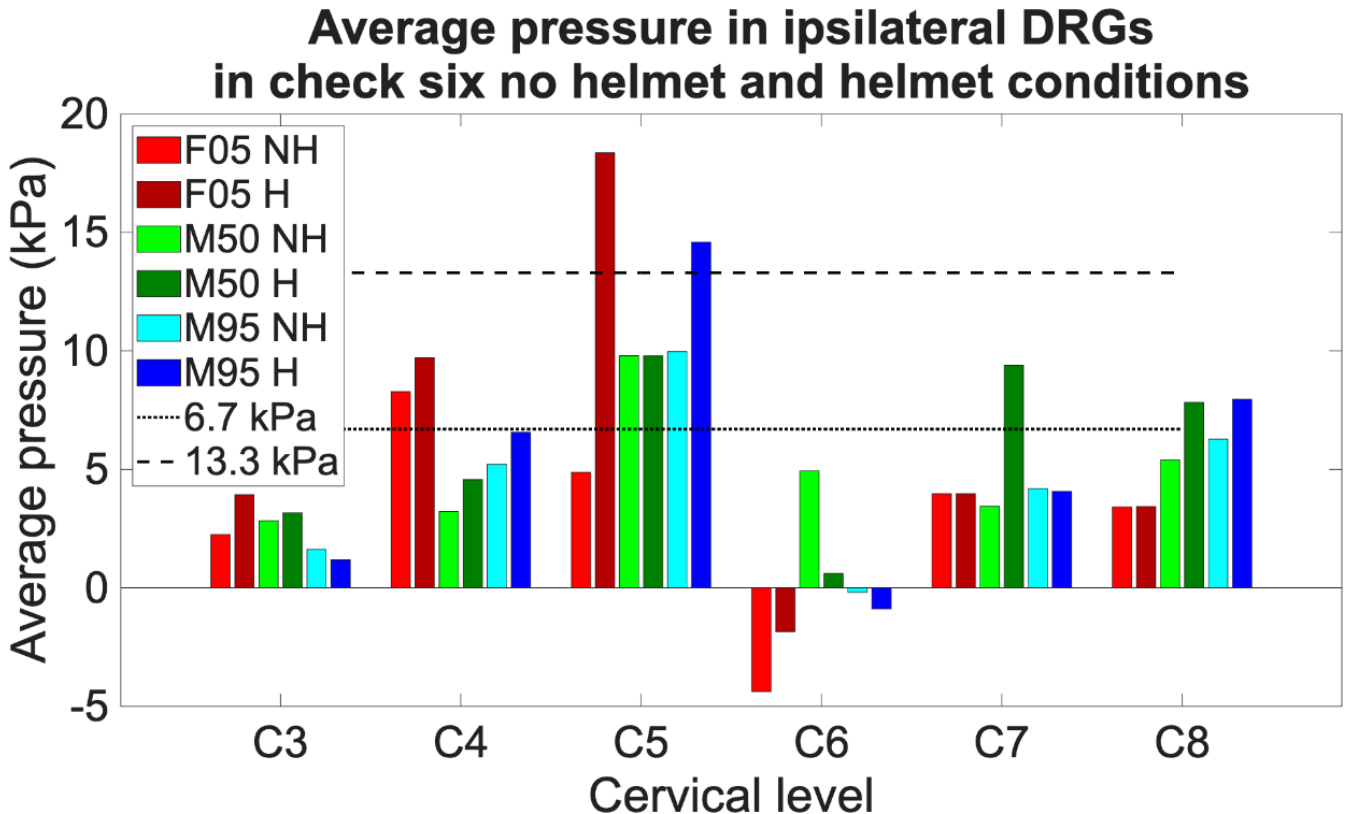
- In axial rotation each model had at least one DRG level exceeding acute pathological levels (6.7kPa)
- The F05 model exceed chronic DRG pressures (13.3 kPa)





Check six - Nerve root pressure

- In check six, each model had at least one DRG level exceeding acute pathological levels (6.7kPa)
- The F05 and M95 models exceed chronic DRG pressures (13.3 kPa)



Discussion

- The combination of helmet loads and strenuous postures display a multifactorial and subject-specific pain mechanisms
- Male models experience greater IVD damage
  - Long term IVD damage can lead to additional NR compression
- Female models experience greater muscle strain and NR compression
  - Long term muscle strain can increase spinal instability and lead to IVD damage
- Subject-specific protocols and therapies crucial for mitigating pain, improving quality of life, and lengthening careers for military personnel

Thank you!

Questions?