A Numerical Investigation of Rider Injury Risks From Falling off an E-scooter

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Prof. Costin Untaroiu

Dr. Costin Untaroiu is currently an Associate Professor of Biomedical Engineering & Mechanics at Virginia Tech. Dr. Untaroiu has a vast experience in the field of Computational Mechanics and Biomechanics. He is co-author of more than 80 peer reviewed journal papers and more than 100 conference papers. Dr. Untaroiu has extensive experience in rigid-body and finite-element modeling, including probabilistic models. He is also a Fellow of ASME.

Education

PhD, Mech. & Aero. Engineering, Univ. of Virginia May 2005
Diploma (BS & MSc) Applied Mathematics: Solid Mechanics May 1996
University of Bucharest, Romania
Diploma (BS & MSc) Mechanical Engineering May 1990
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Professional Experience

Associate Professor of Biomedical Engineering 2015-present
Research Associate Professor 2011-2015
Virginia Tech and Wake Forest University
Research Assistant Professor 2008-2011, Univ. of Virginia

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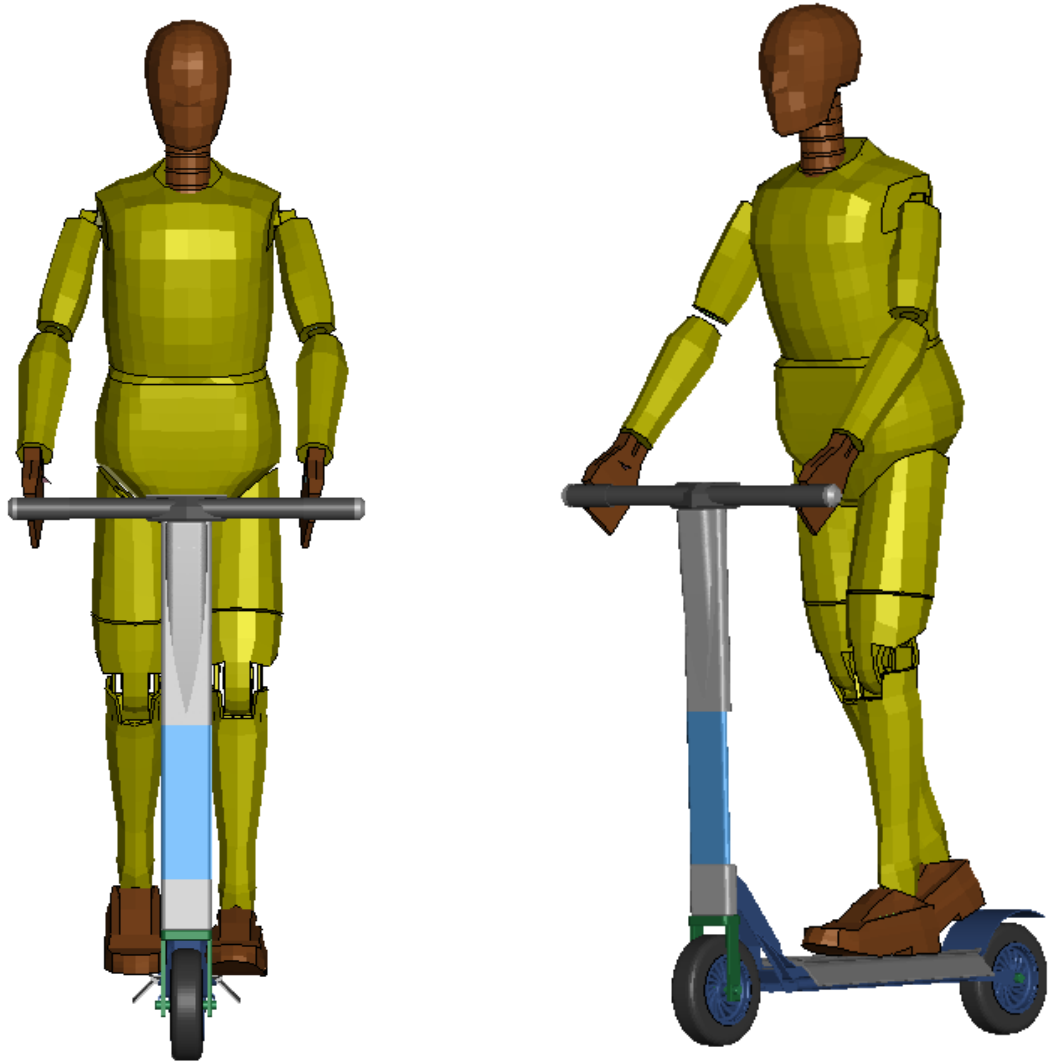
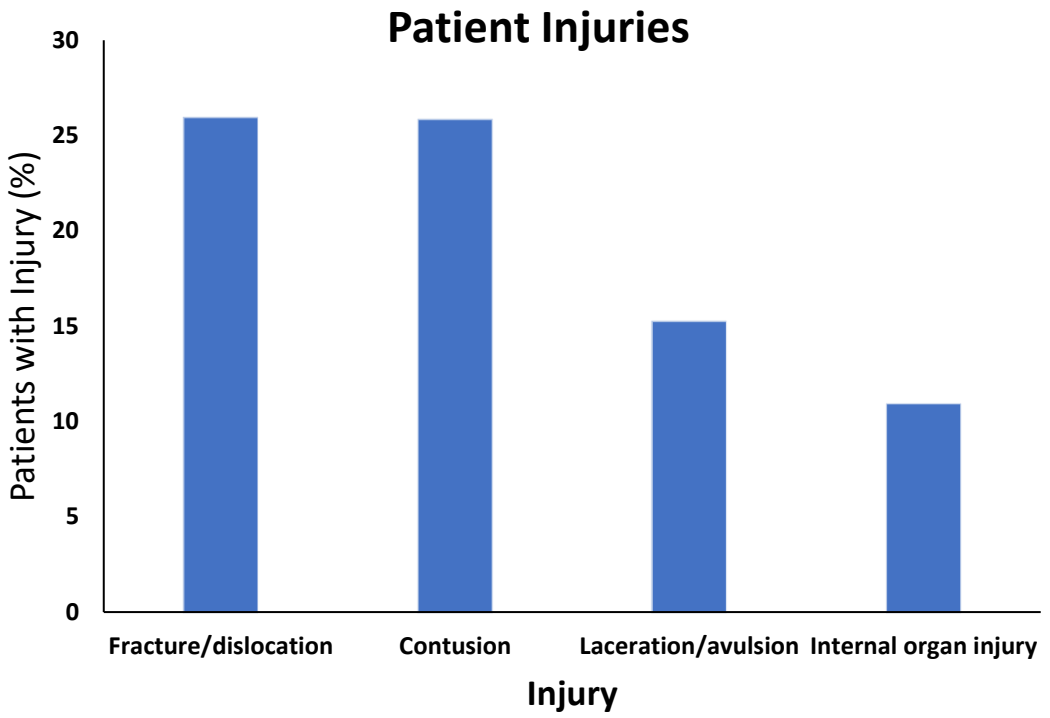


1. Introduction

- Head and limbs most frequently injured regions [1]
- Fractures/dislocations and contusions are the most common types of injuries [1]
- Most e-scooter crashes are caused by falls



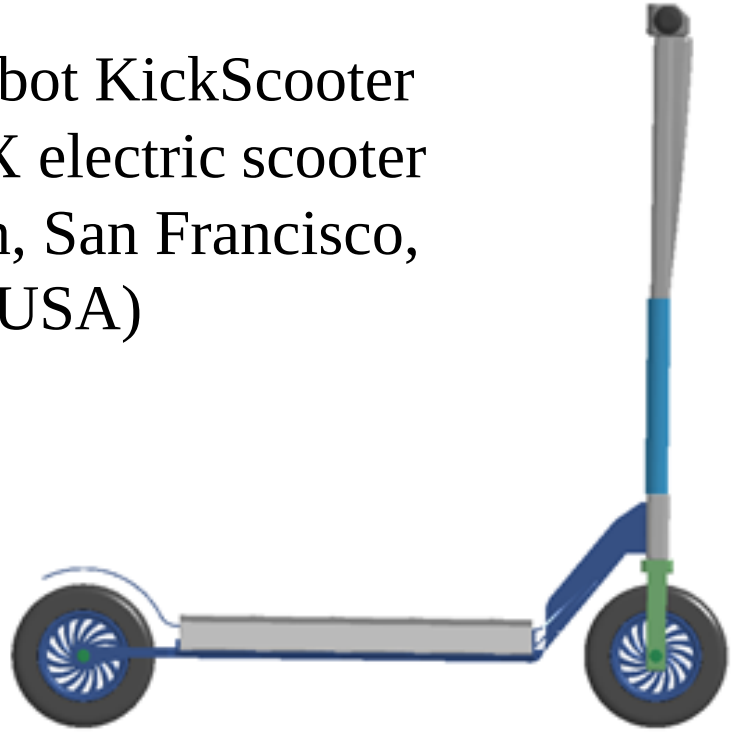
Data taken from Aizpuru et al. [1]

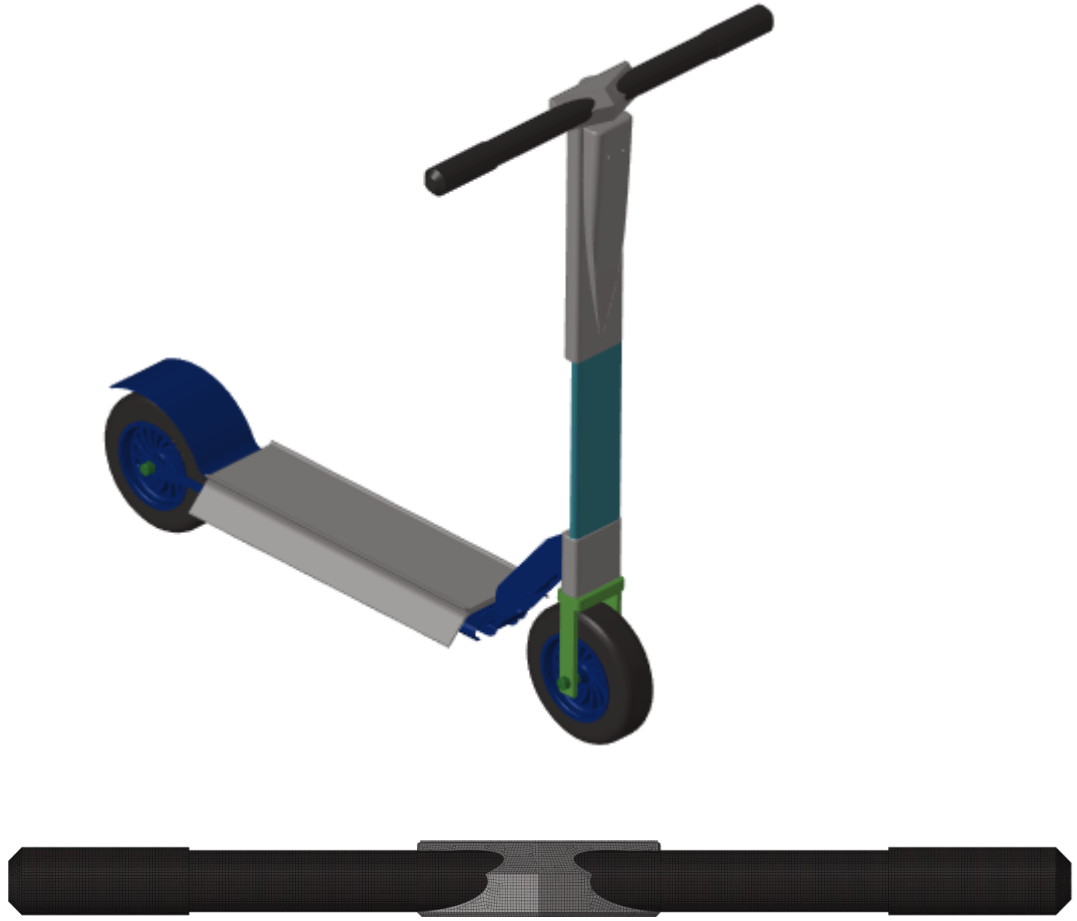
2. Methods: FE setup of Scooter Accident Simulation

- Dummy model used was of a standing 50% male Hybrid III dummy (78.1 kg, 1700 mm height). The FE model contained 4,301 elements and 7,355 nodes (LSTC/Ansys model).
- Flat ground created
  - Deformable top layer
    - Concrete material
  - Rigid bottom layer created to keep top layer stationary
- A stopper placed in path of scooter

2. Methods : Geometry Reconstruction & Meshing

Ninebot KickScooter MAX electric scooter (Spin, San Francisco, CA, USA)



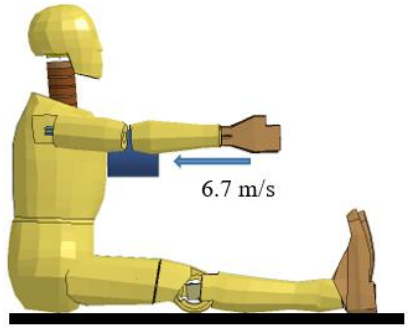


FARO laser scanner system (Point clouds) → Rhino 3D (NURBS surfaces) → HyperMesh (model mesh)

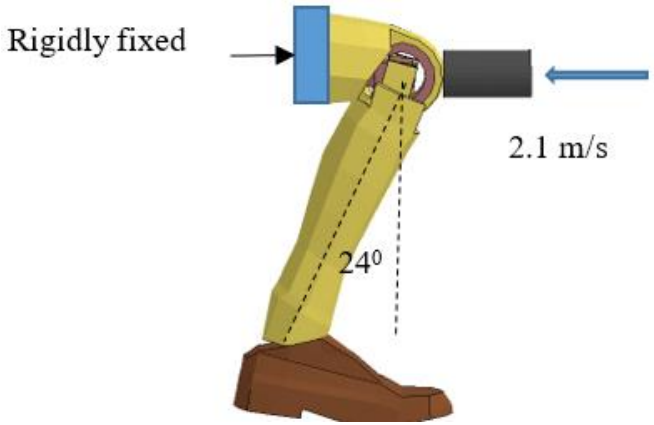
2. Methods: Calibration of HIII FE Model

- Several tests were simulated and used to calibrate the HIII model

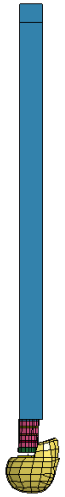
Head drop test



Thorax Impact Test

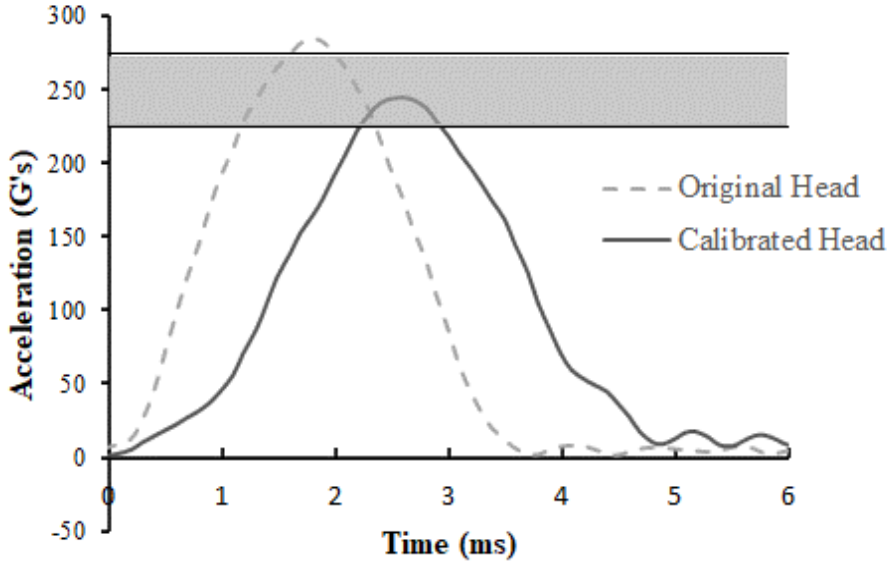


Knee Impact Test



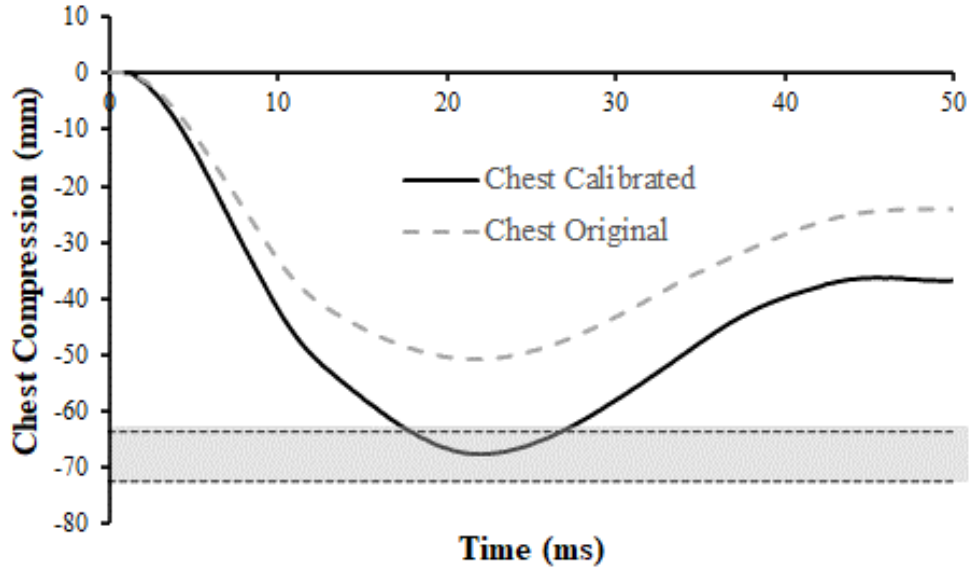
Neck Pendulum extension/flexion Tests

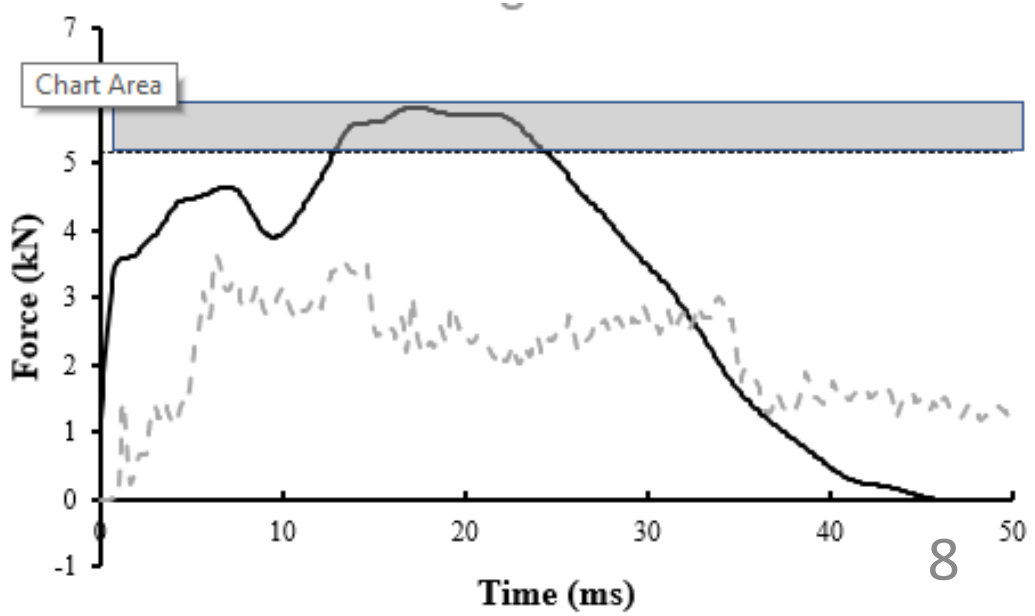
3. HIII Calibration Example: Head and Thorax Calibration



Head Calibration

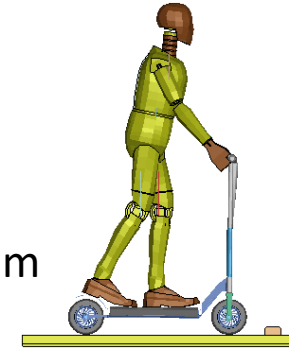
Thorax Calibration

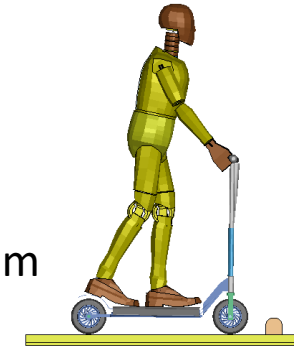


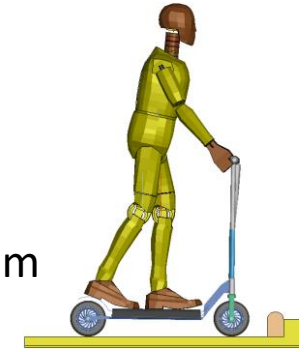


3. Impact Simulations: Impact variables tested

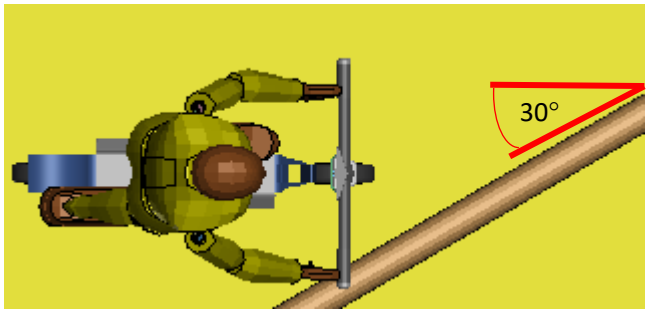
- Stopper height

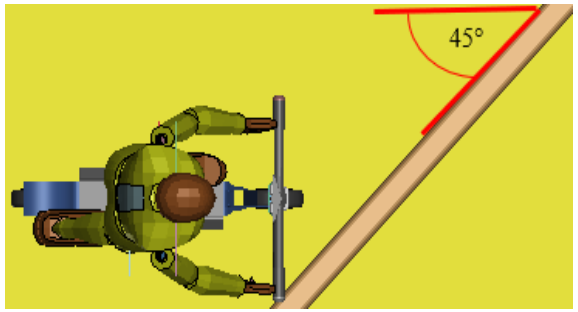
52 mm 

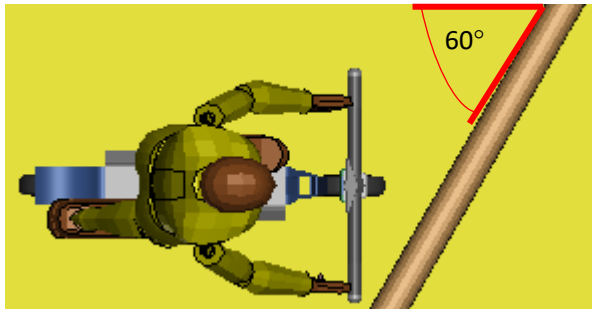
101 mm 

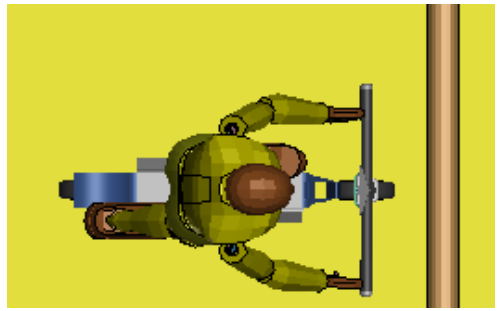
152 mm 

- Approach angle









- Impact speed
  - 3.2 m/s
  - 4.48 m/s
  - 11.16 m/s

3. Impact Simulations: Arm activation

- Arm activation added to all head-on collisions
- Accomplished by loading the shoulder and elbow joints
- Ran a total of 45 e-scooter crash simulations

a) No arm activation

a) Arm activation included

3. Impact Simulations: Injury Risks Calculation

- Injury metrics extracted from simulations
  - Head injury criteria (HIC)
  - Neck injury criteria (N_{ij})
  - Chest Deflection
  - Maximum femur force
- Used to calculate Rider Injury Measure (RIM)

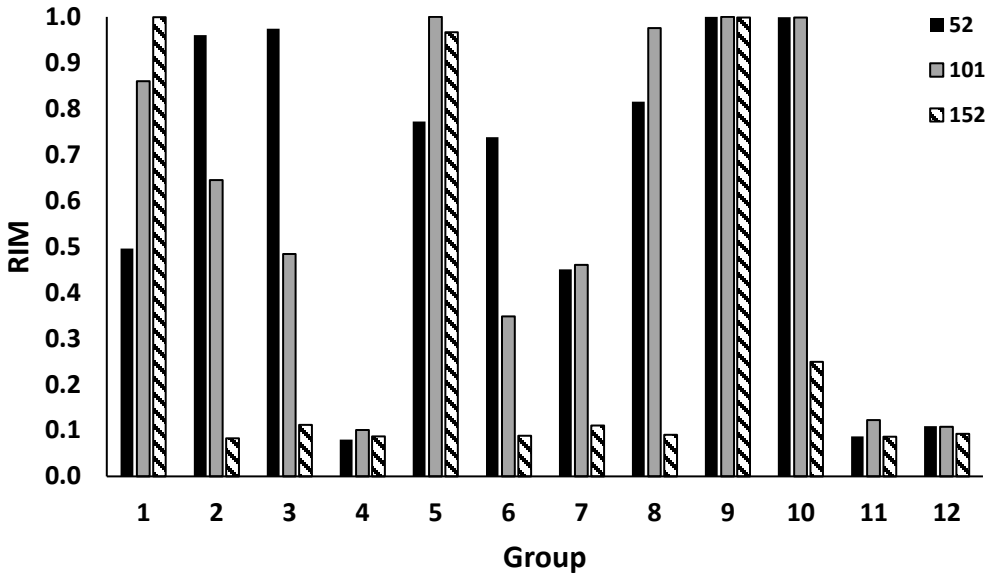
$$RIM_{AIS3+} = 1 - (1 - P_{HIC}) * \left(1 - P_{N_{ij}}\right) * (1 - P_{chest}) * (1 - P_{femur})$$

3. Impact Simulations: Statistical Analysis

- Correlation coefficients measured the relationship between pre-impact variables and injury risks
- Sobol's global sensitivities compared the effect of each pre-impact variable
- Student t-tests determined if arm activation caused any significant changes to injury risks

4. Results & Discussion: Injury Metrics

- About half of all neck and head injury risks were higher than 25%
- 4 of the 5 lowest RIM scores occurred simulations using smaller approach angles
- Nearly all simulations with RIM scores of 1 occurred during head-on collisions



4. Results & Discussion: Approach Angle

- The approach angle had strong positive correlations with head, neck, chest, and overall injury risks
- E-scooter impacting a 52 mm stopper at 11.16 m/s
  - Head-on collision

  - 30° approach angle

4. Results & Discussion: Impact Speed

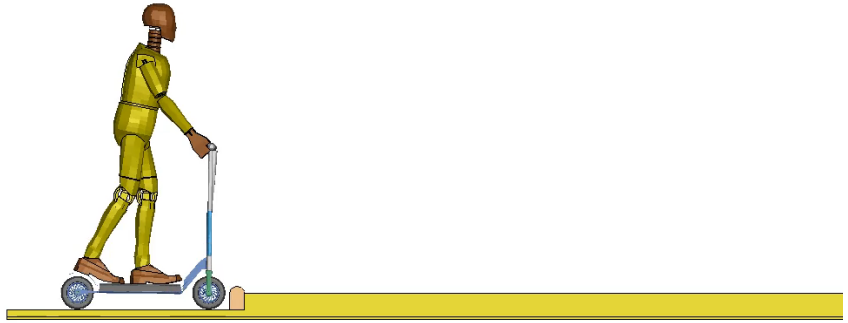
- The impact speed had small negative correlations with RIM and chest injury and small positive correlations with head, neck, and chest injury risks
- E-scooter impacting a 52 mm stopper with a 90° approach angle
  - 3.2 m/s impact speed

  - 11.16 m/s impact speed

4. Results & Discussion: Stopper Height

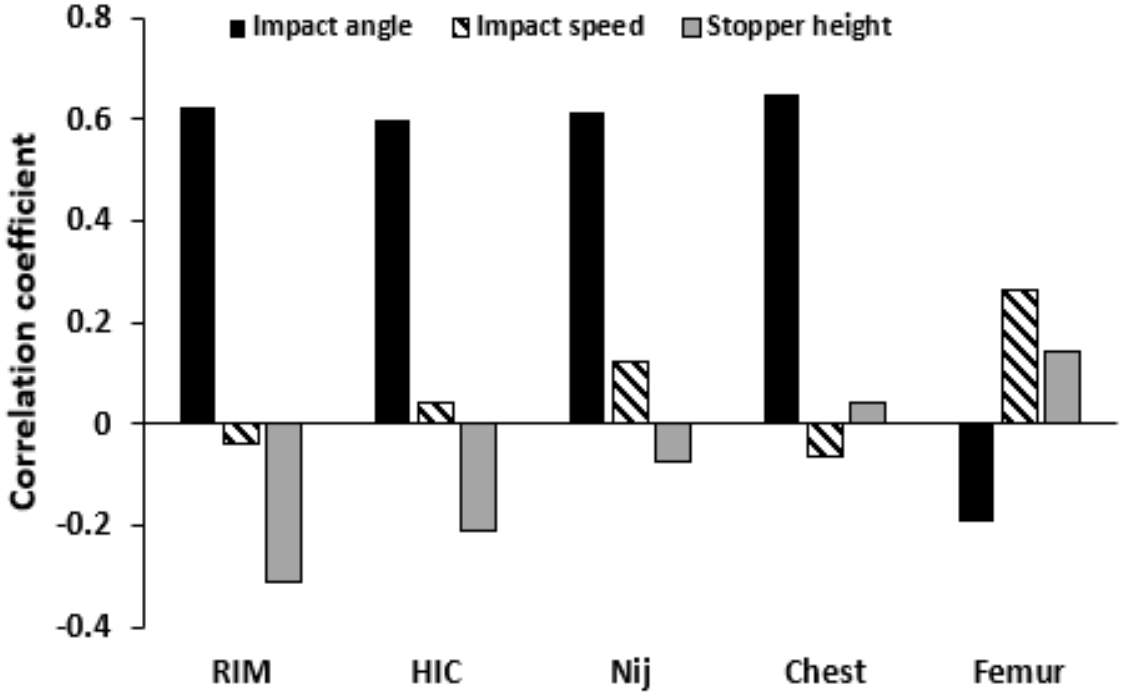
- Stopper height had the lowest contribution to injury risk
- E-scooter impacting a stopper with a 90° approach angle at 3.2 m/s
  - 52 mm stopper

  - 152 mm stopper

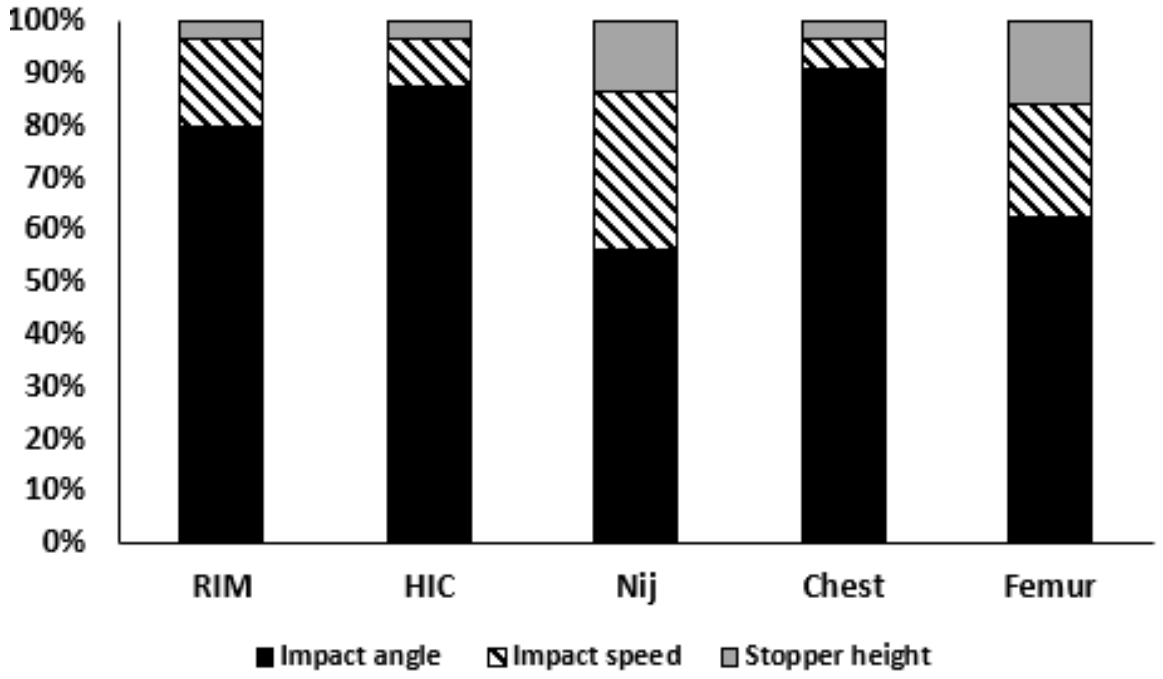


4. Results & Discussion: Correlation Coefficients and Global Sensitivities

Correlation Coefficients

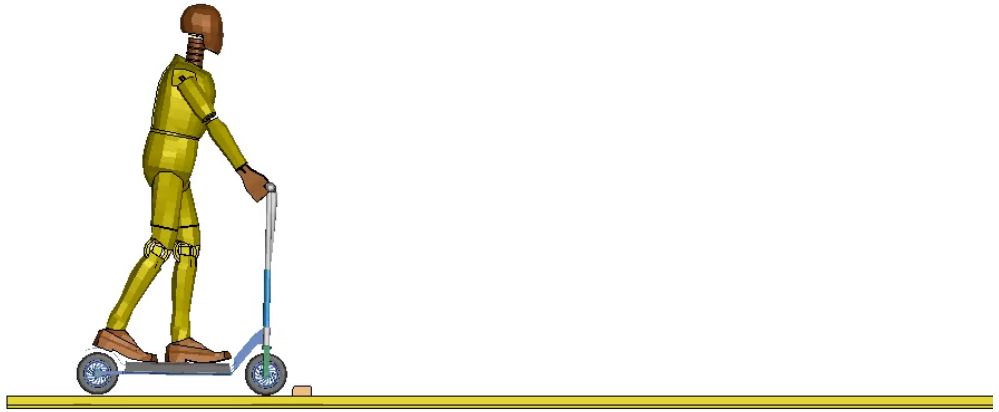


Global Sensitivities



4. Results & Discussion: Arm Activation

- Reduced RIM scores were reduced in two-thirds of the head-on crash simulations
- Arm activation had a statistically significant effect on neck injury risk ($p=0.042$)
- E-scooter impacting a 52 mm stopper at a speed of 3.2 m/s



4. Results & Discussion: Key points

- Key conclusions
  - The approach angle had the greatest impact on injury risk
  - The impact speed had a negative correlation with injury risks for small angles of approach
  - Overall arm activation did reduce RIM scores

- Limitations
  - Limited selection of injury measures
  - Coarse HIII dummy model

5. Conclusions

- Risks of serious injury were greatest for the head and neck regions
  - Corroborated by experimental data [2]
- A future study will look at impacts involving a collisions with vehicles
- This study showed a higher risk of serious injury than observed in hospitals

6. Acknowledgements

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7. References

[1] Aizpuru, M., Farley, K. X., Rojas, J. C., Crawford, R. S., Moore Jr, T. J., and Wagner, E. R., 2019, "Motorized scooter injuries in the era of scooter-shares: a review of the national electronic surveillance system," The American Journal of Emergency Medicine, 37(6), pp. 1133-1138.

[2] Trivedi, T. K., Liu, C., Antonio, A. L. M., Wheaton, N., Kreger, V., Yap, A., Schriger, D., and Elmore, J. G., 2019, "Injuries associated with standing electric scooter use," JAMA network open, 2(1), pp. e187381-e187381.