Validation of the 3-RCS: A Biomechanical Surrogate for Blunt Ballistic Impacts to the Thorax

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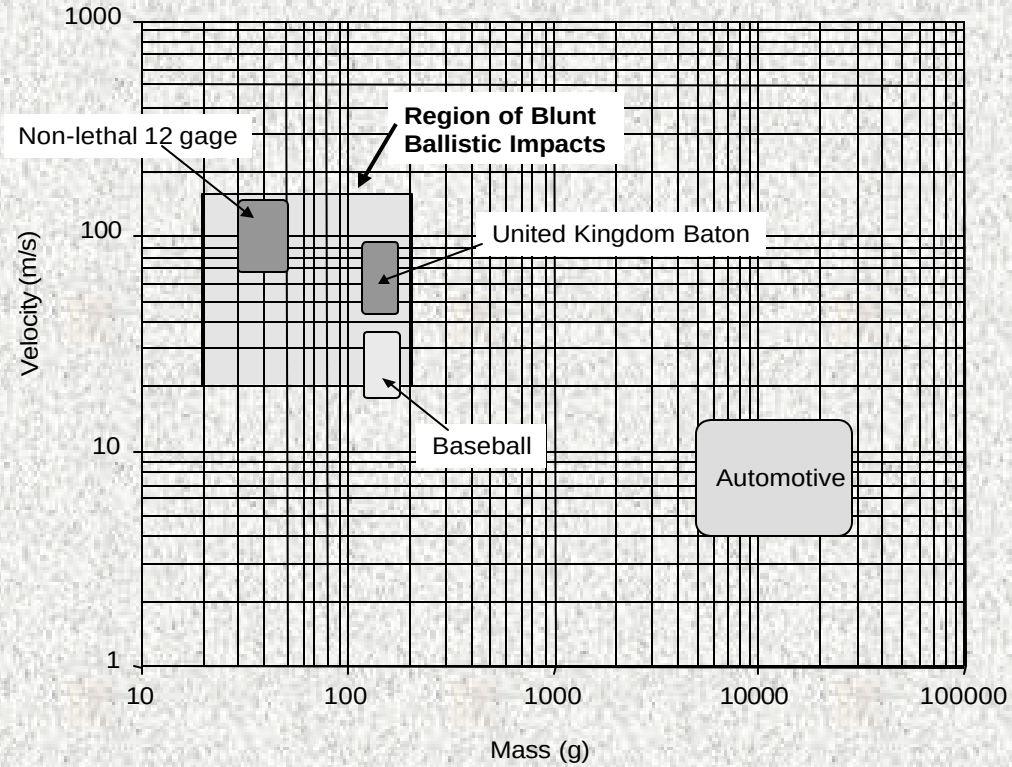
Regions of blunt impact testing



Blunt ballistic impacts:
impactor mass of 20-200 g
impact velocity of 20 -250 m/s

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Human Response to Blunt Ballistic Impacts

- Biomechanical testing
- 13 cadavers (10 used in final analysis)
  - University of Michigan - Anatomical Donations
  - Wayne State - Willed Body Program
- Pre-established impact conditions

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Impact Conditions

- *Impact A*) A stiff baton with mass (M) of 140 grams, length (L) of 100 mm and effective diameter (D) of 37 mm launched at 20 m/s.

- *Impact B*) A stiff baton with mass (M) of 140 grams, length (L) of 100 mm and effective diameter (D) of 37 mm launched at 40 m/s.

- *Impact C*) A stiff baton with mass (M) of 30 grams, length (L) of 28.5 mm and effective diameter (D) of 37 mm launched at 60 m/s.

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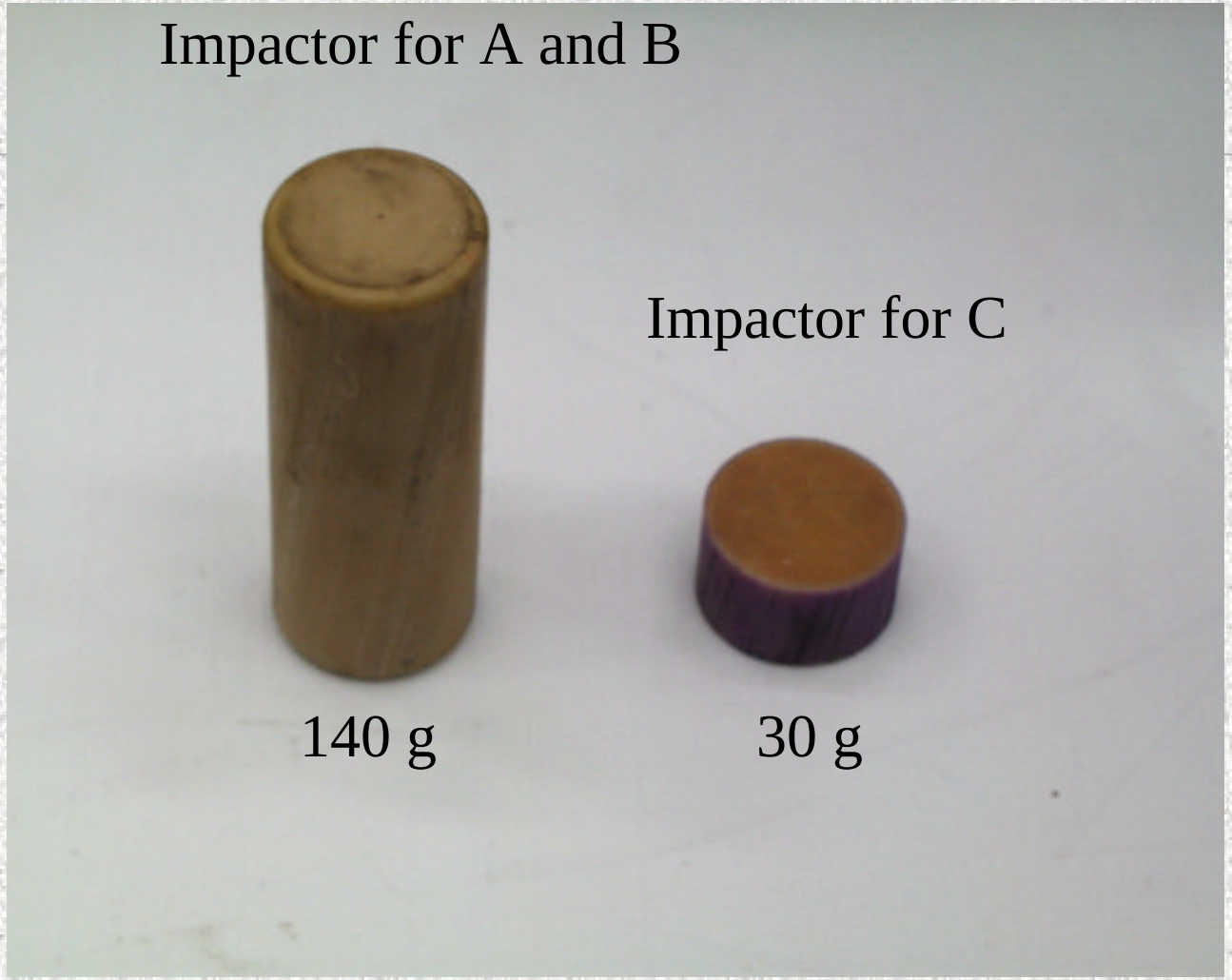

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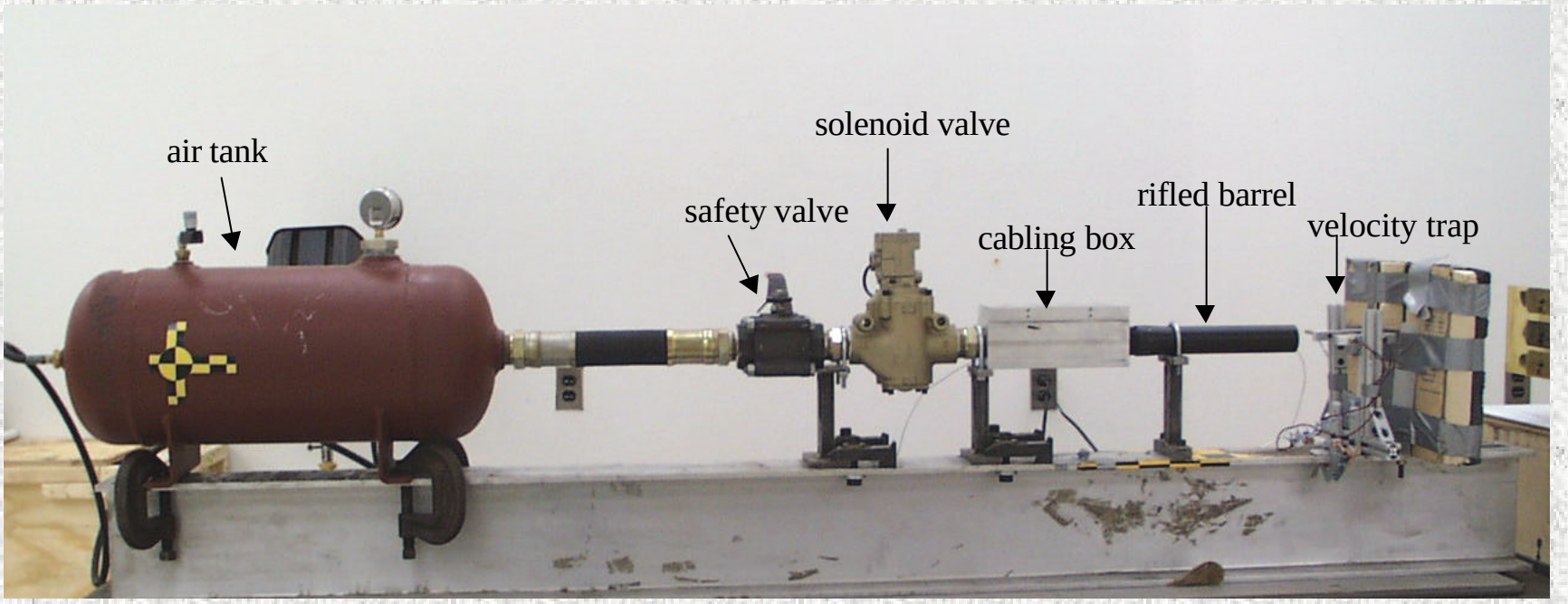
Ballistic air cannon



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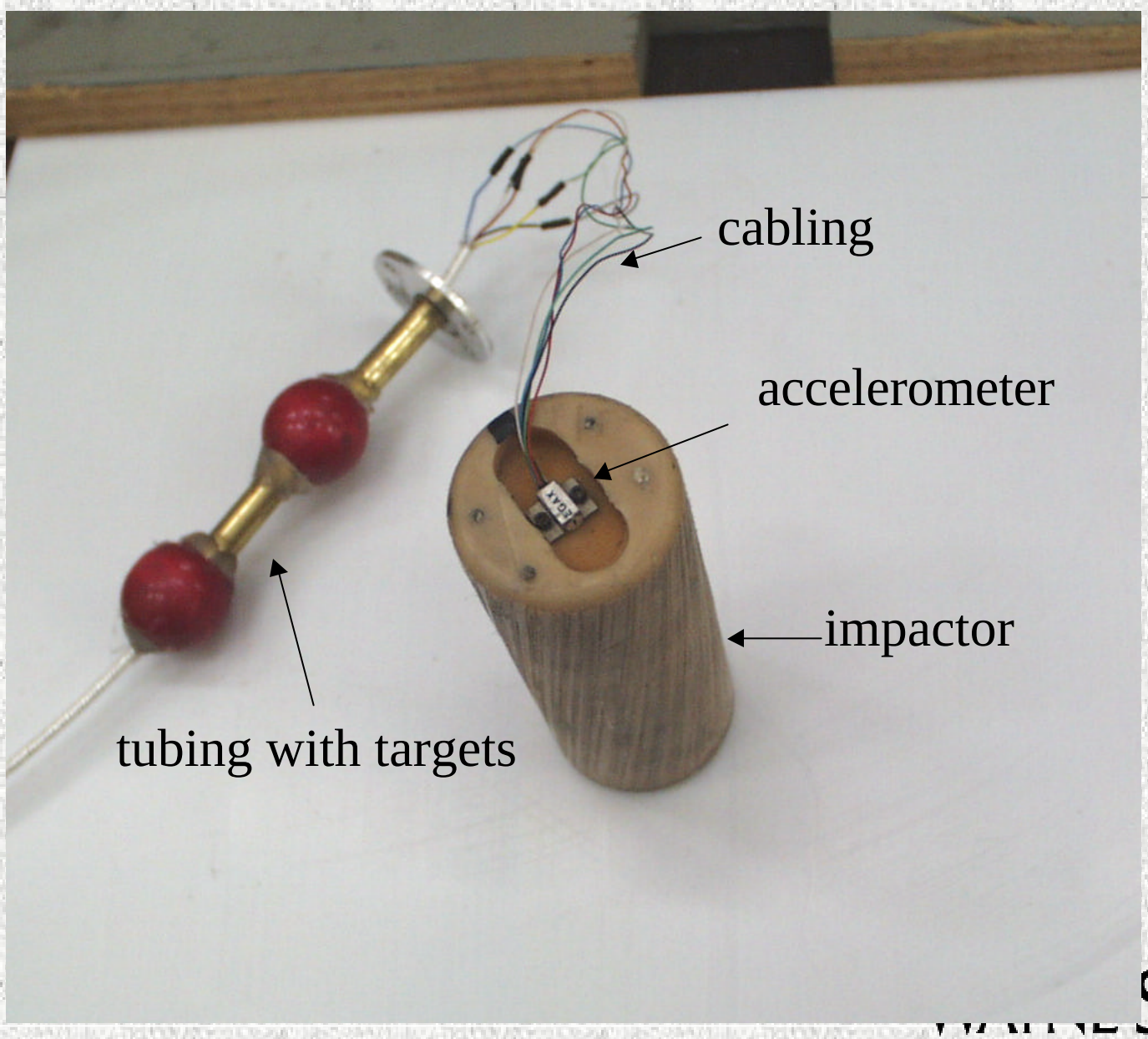

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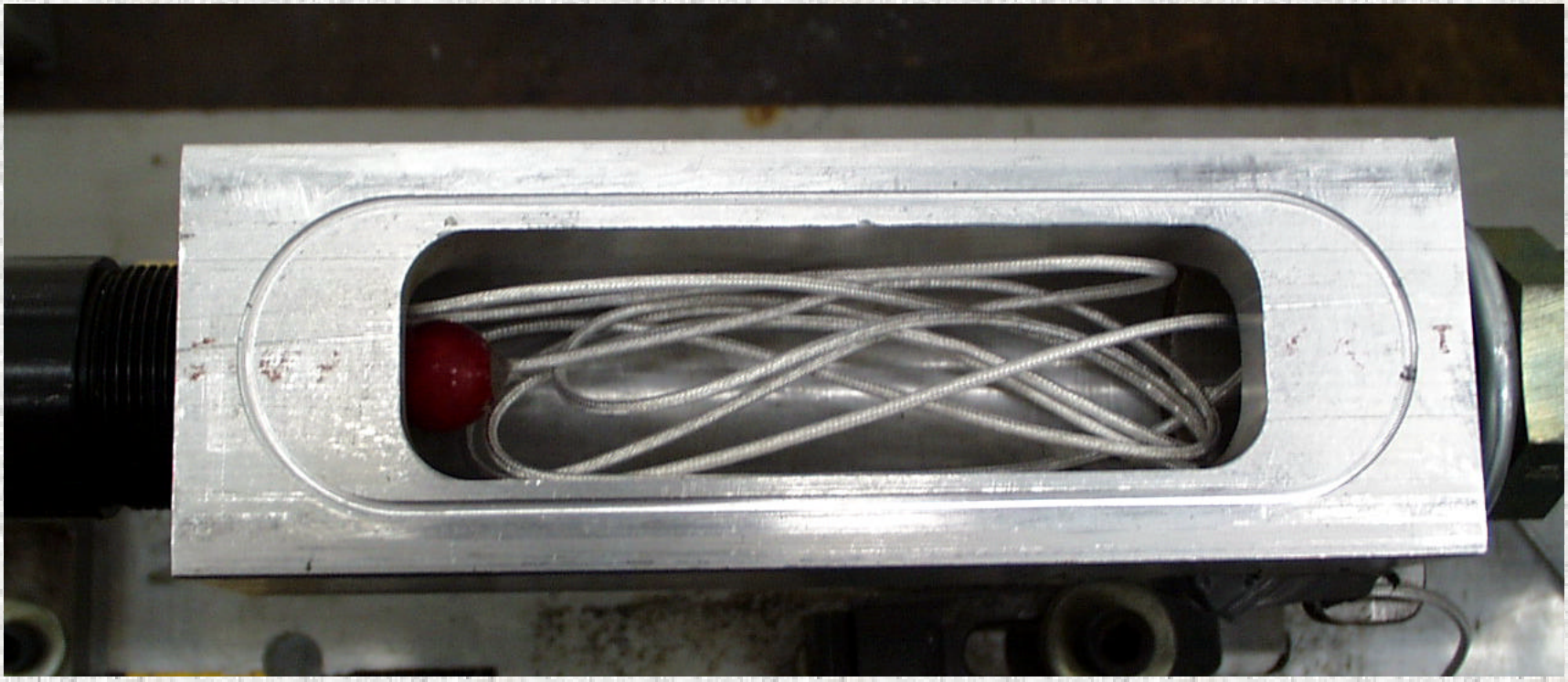
Cabling box



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Anthropometric data for cadaveric specimens

Test #	Specimen #	Age (years)	Gender	Mass (kg)	Stature (cm)	Thorax Breadth	Thorax Depth (cm)	Thorax Circumference
NIJ 1	29131	88	M	72	156	35.0	24.0	99.0
NIJ 2	29116	78	M	52	162	28.0	19.0	83.0
NIJ 3	29383	75	M	38	155	27.5	17.0	79.2
NIJ 4	599	68	F	75	165	28.0	19.0	97.0
NIJ 5	29540	71	M	69	172	29.0	23.4	94.0
NIJ 6	29422	76	F	75	171	33.5	22.5	101.0
NIJ 7	29606	66	M	74	178	30.4	25.3	100.8
NIJ 8	29605	74	M	82	181	32.5	22.7	101.0
NIJ 9	29676	76	F	71	158	35.0	20.2	103.0
NIJ 10	29610	70	F	79	168	34.9	19.5	104.0
NIJ 11	29589	76	M	107	174	37.9	25.0	114.0
NIJ 12	864	76	F	72	168	35.4	21.9	107.5
NIJ 13	29543	56	M	82	178	36.7	28.0	109.0

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Normalization to 50th percentile male

- λ = chest depth of 50th percentile male (236 mm) / specimen chest depth

- Normalized displacement = displacement * λ
- Normalized force = force * λ^2
- Normalized acceleration = acceleration * λ^{-1}
- Normalized time = time * λ

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Summary of tests included in analysis

Test ID	Impactor A 140 g @ 20 m/s	Impactor B 140 g @ 40 m/s	Impactor C 30 g @ 60 m/s
NIJ 4		X	
NIJ 5	X		X
NIJ 6			X
NIJ 7		X	
NIJ 8	X	X	
NIJ 9			X
NIJ 10	X	X	X
NIJ 11	X	X	X
NIJ 12	X		X
NIJ 13	X	X	X

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Biomechanical responses

- Force-time curves
  - acceleration data from impactor
- Deflection-time curves
  - film (6000 fps)/ video (9000 fps)
- Force-deflection curves

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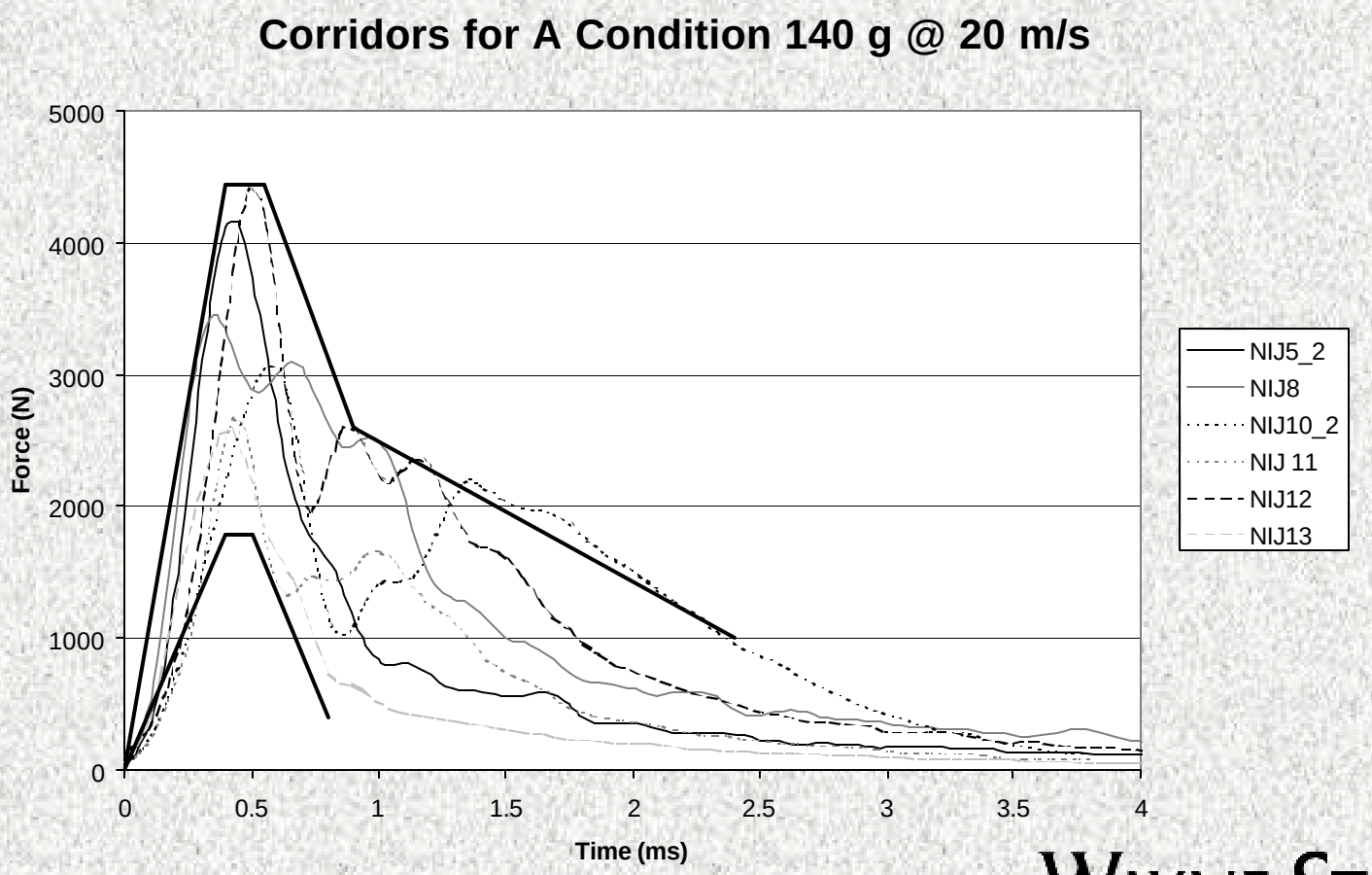
Corridors - A Condition



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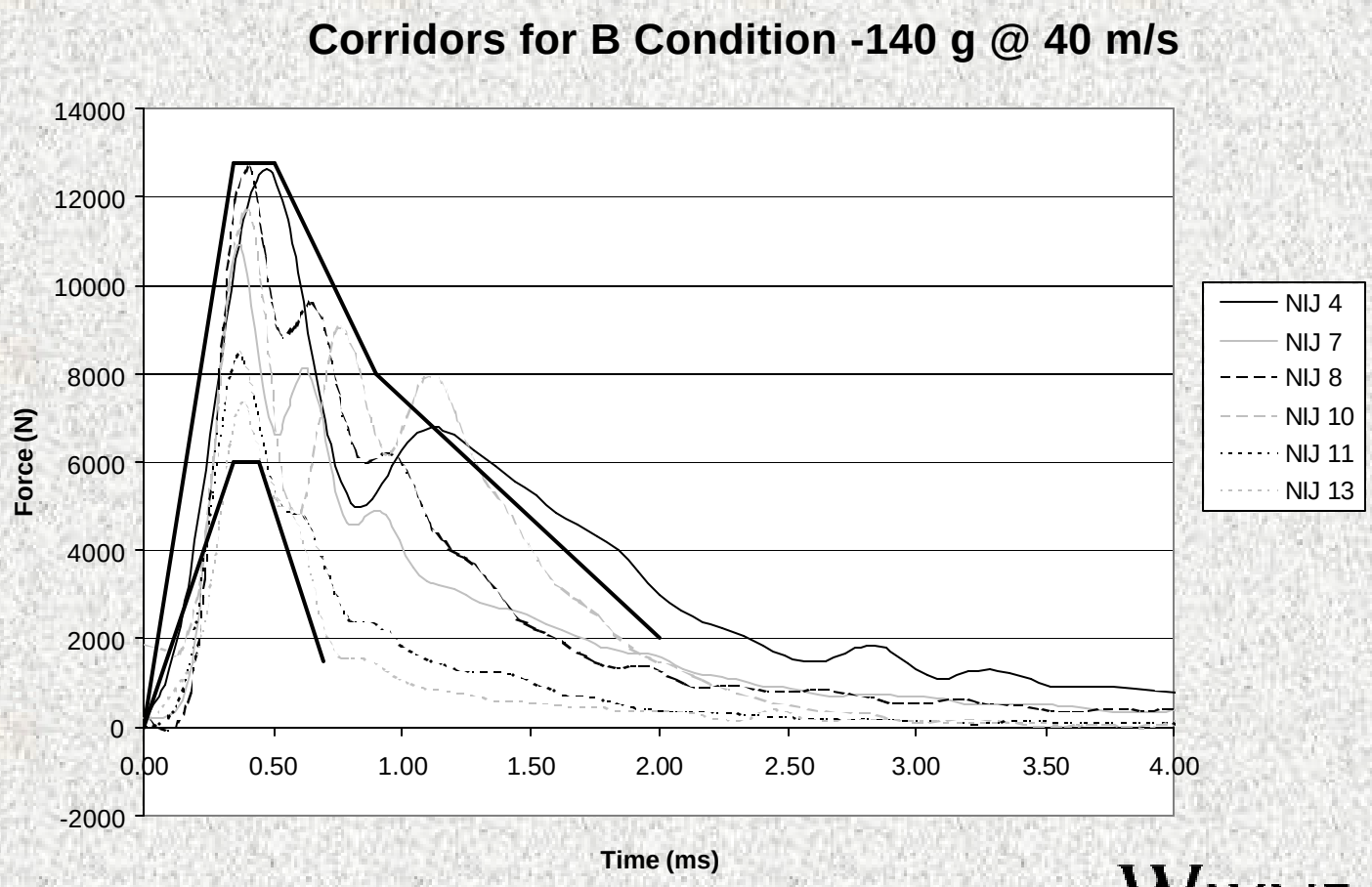
Corridors - B Condition



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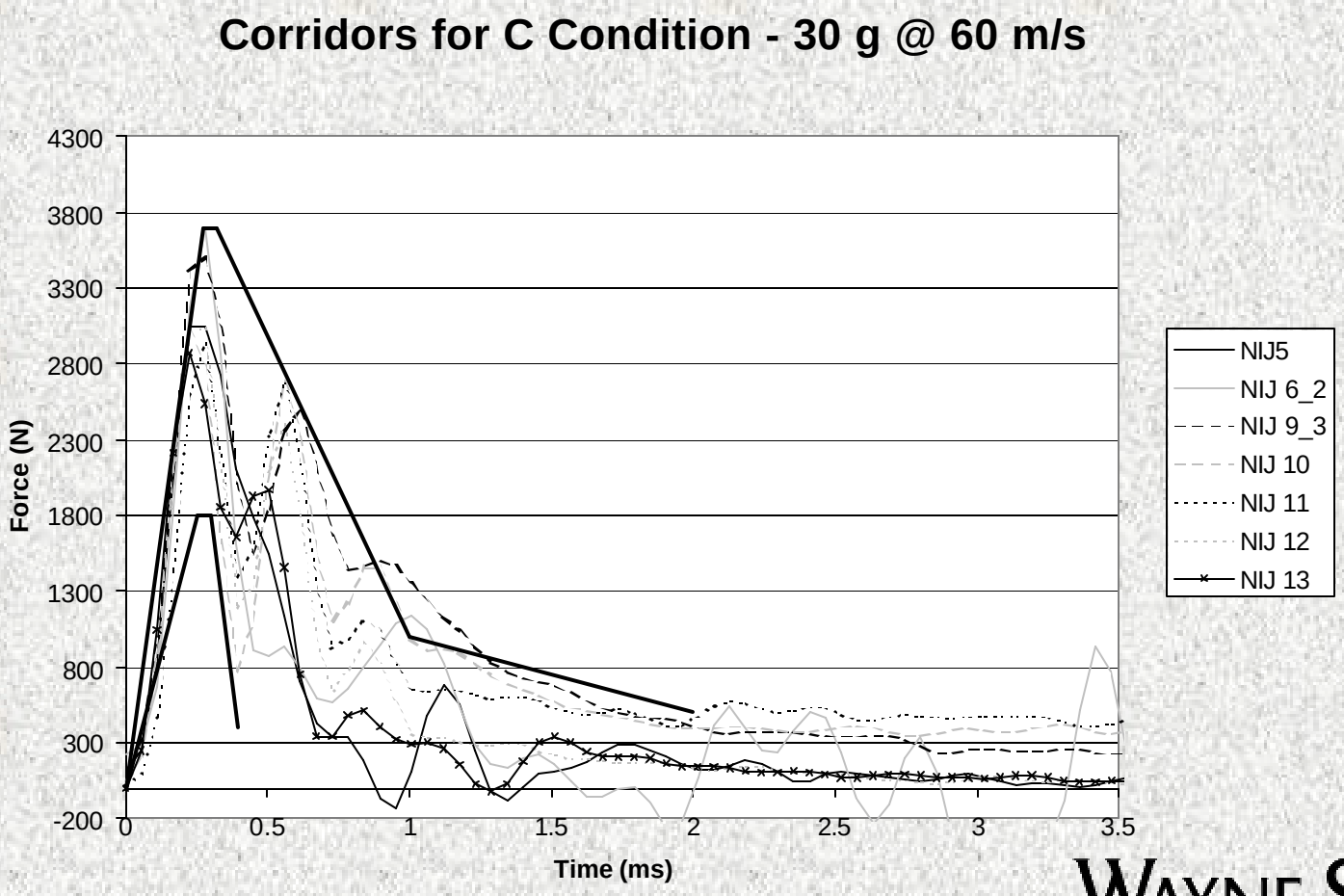
Corridors - C Condition



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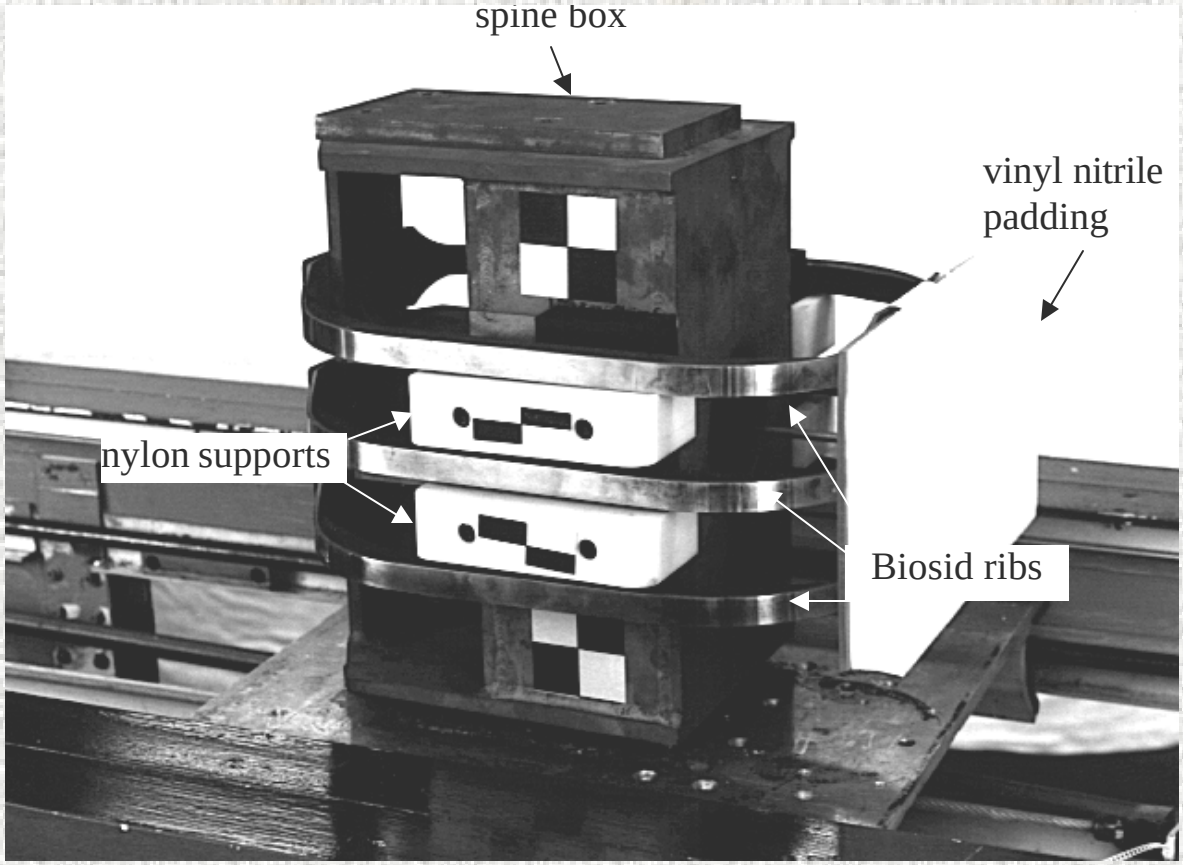
3-Rib Chest Structure



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Validation of 3-RCS

- Tested with same impact conditions
- Results compared to established corridors
- Iterative process (original)
  - mass (18.1 kg)
  - padding material (vinyl nitrile -18 mm thick)

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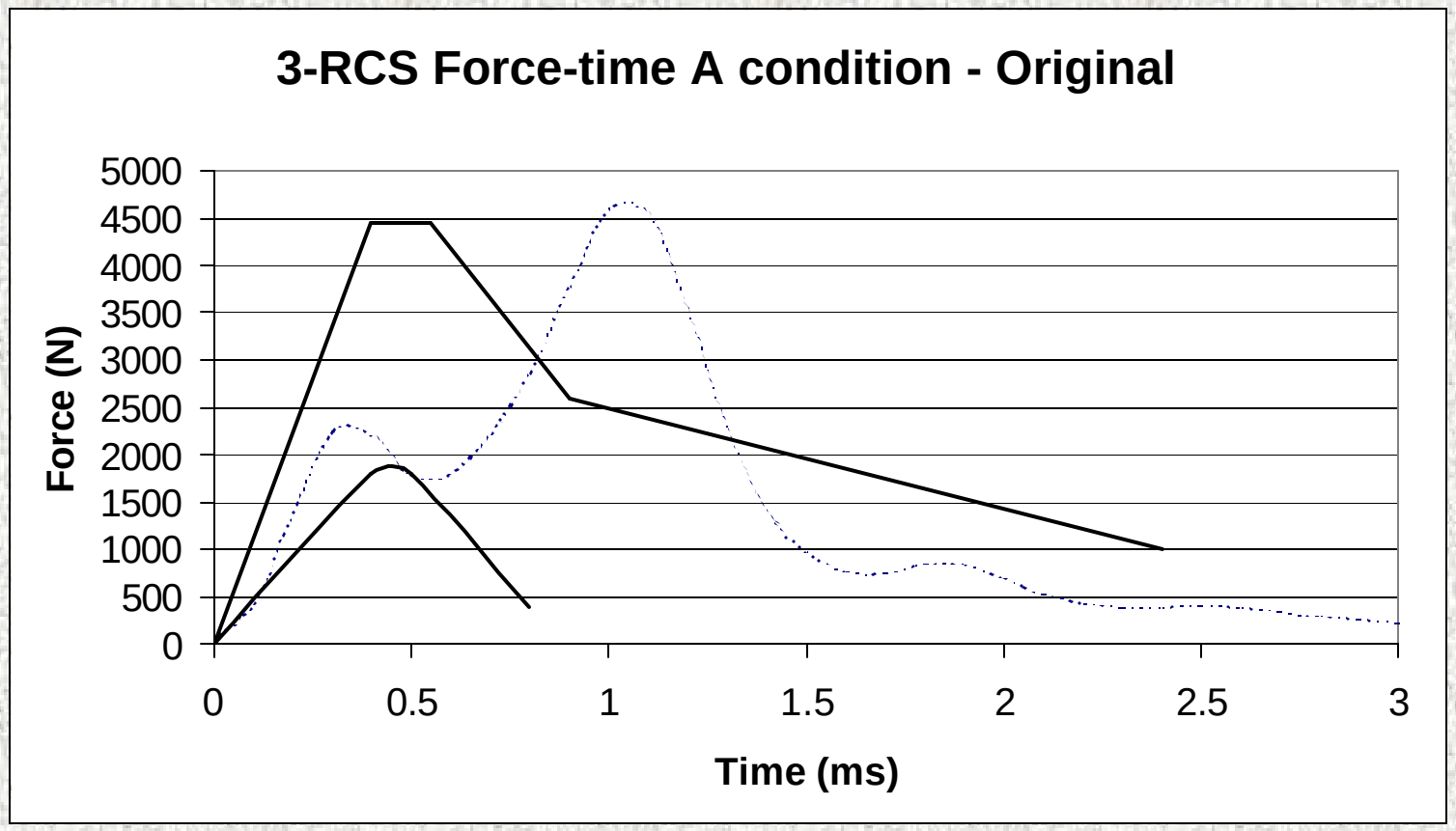
Results with original configuration



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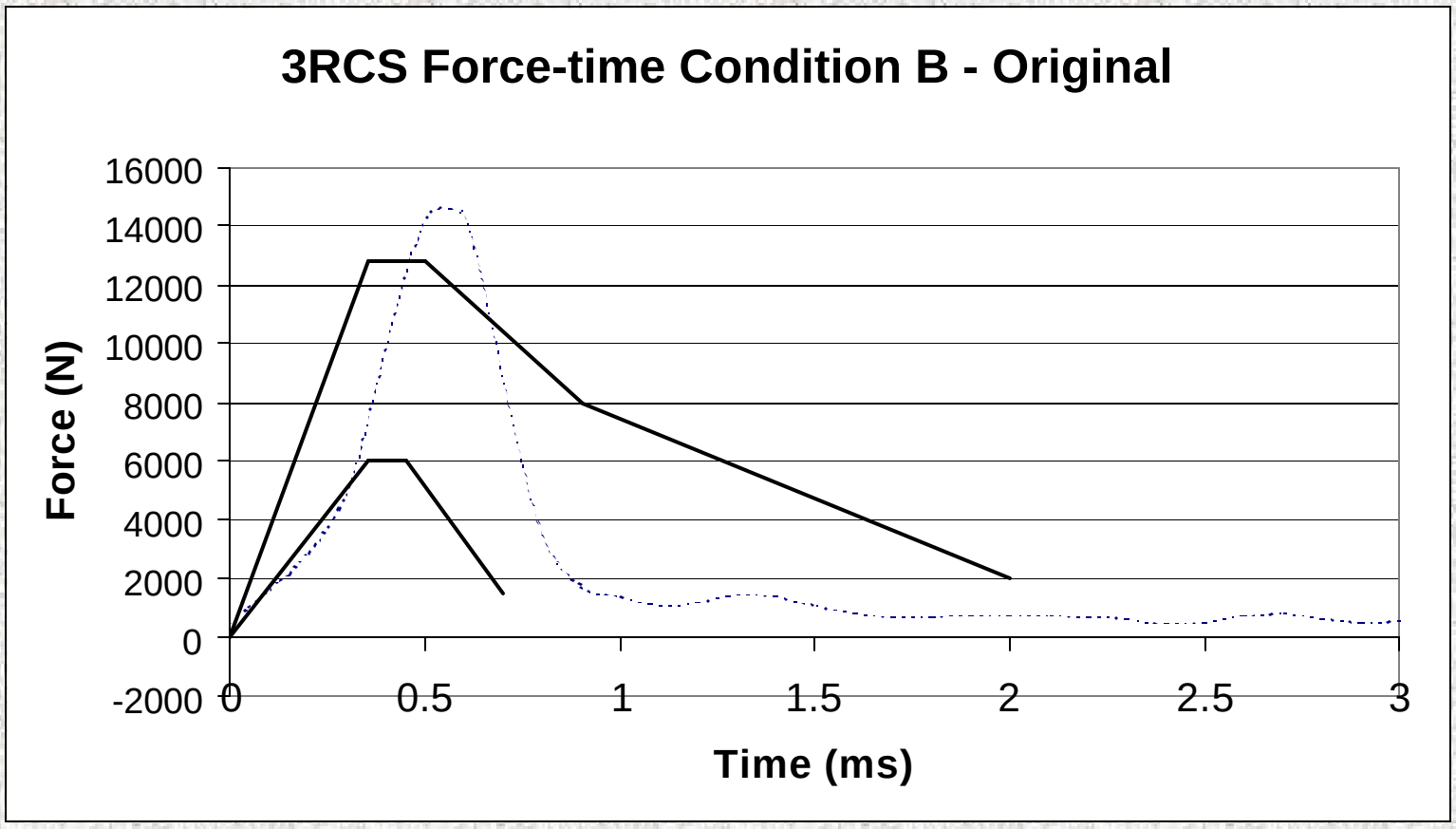

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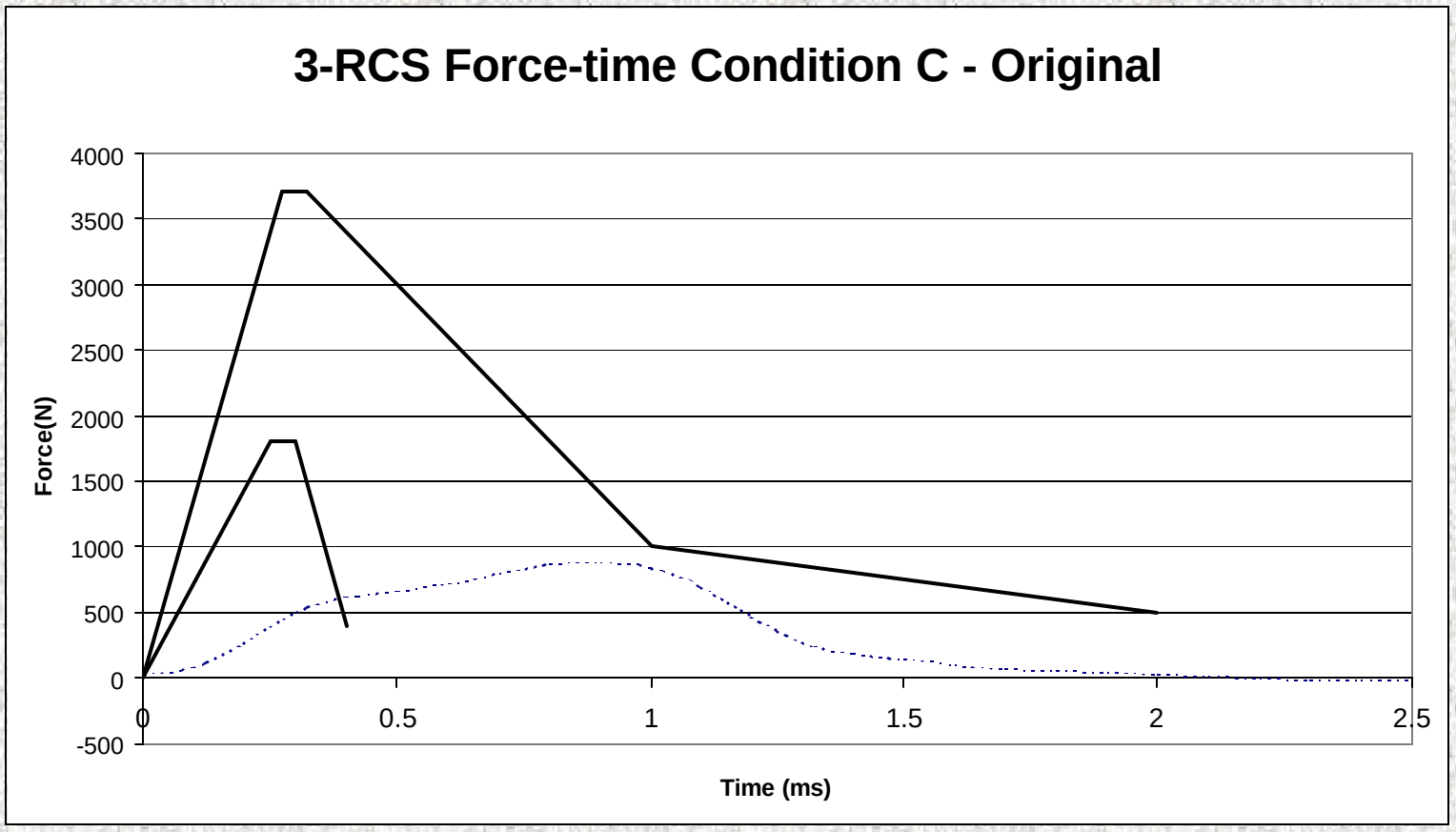

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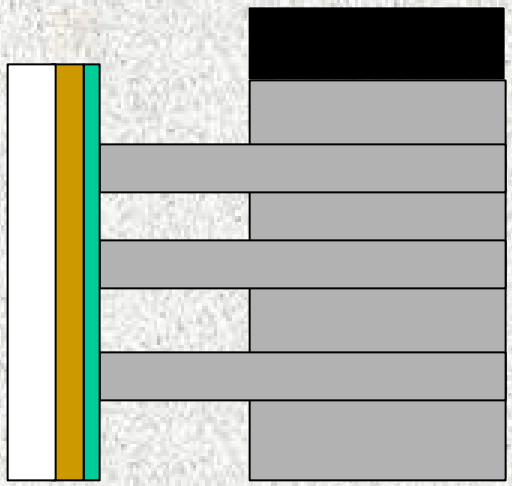
Results of Iterative Process

- Mass added to spine box
  - 23 kg added to existing 18.1 kg mass = 41.1 kg
- Cork layer added
  - 10 mm of cork
- Padding material changed
  - mini-cell polyethylene (18 mm)



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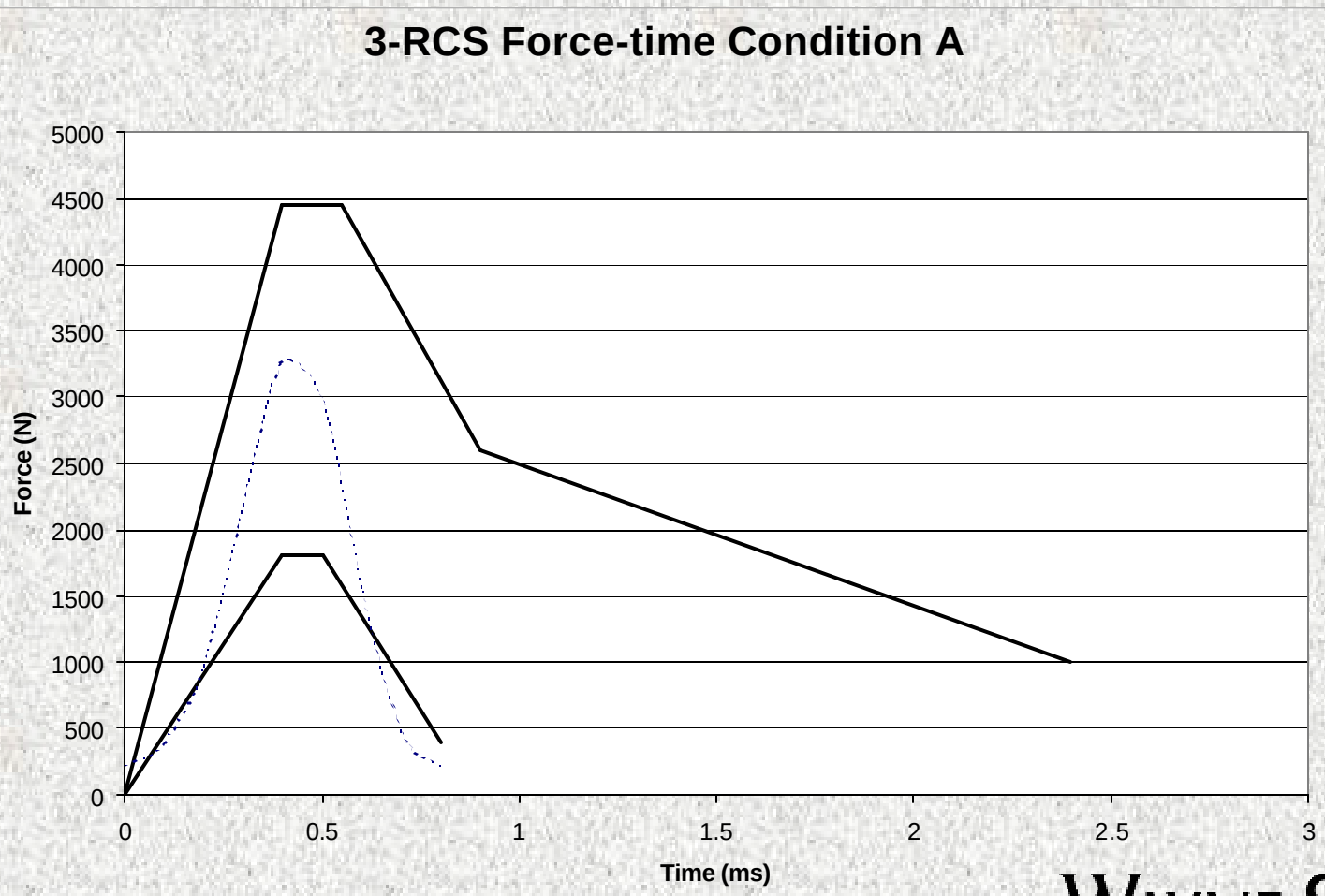
Revised 3-RCS - A Condition



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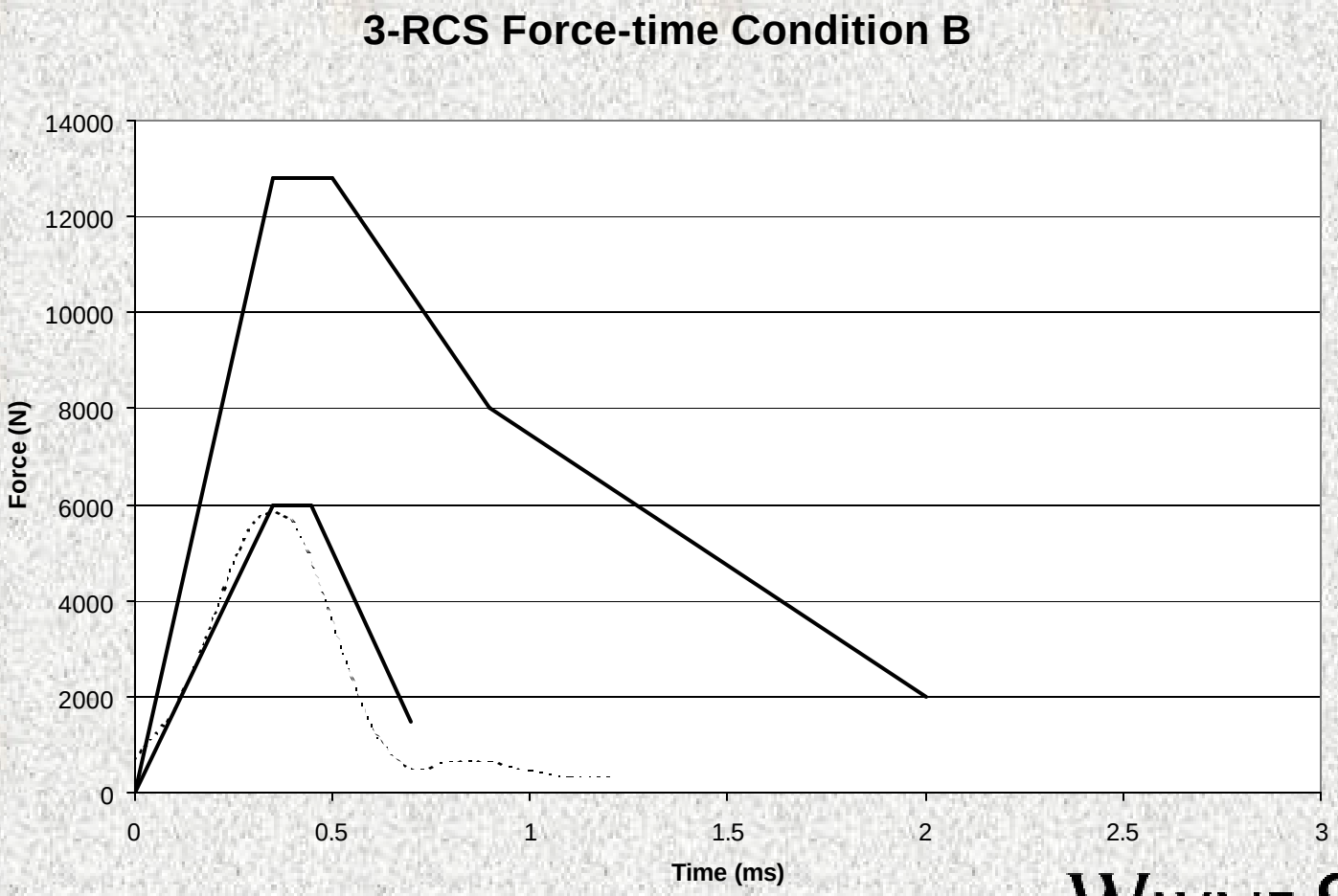
Revised 3-RCS - B Condition



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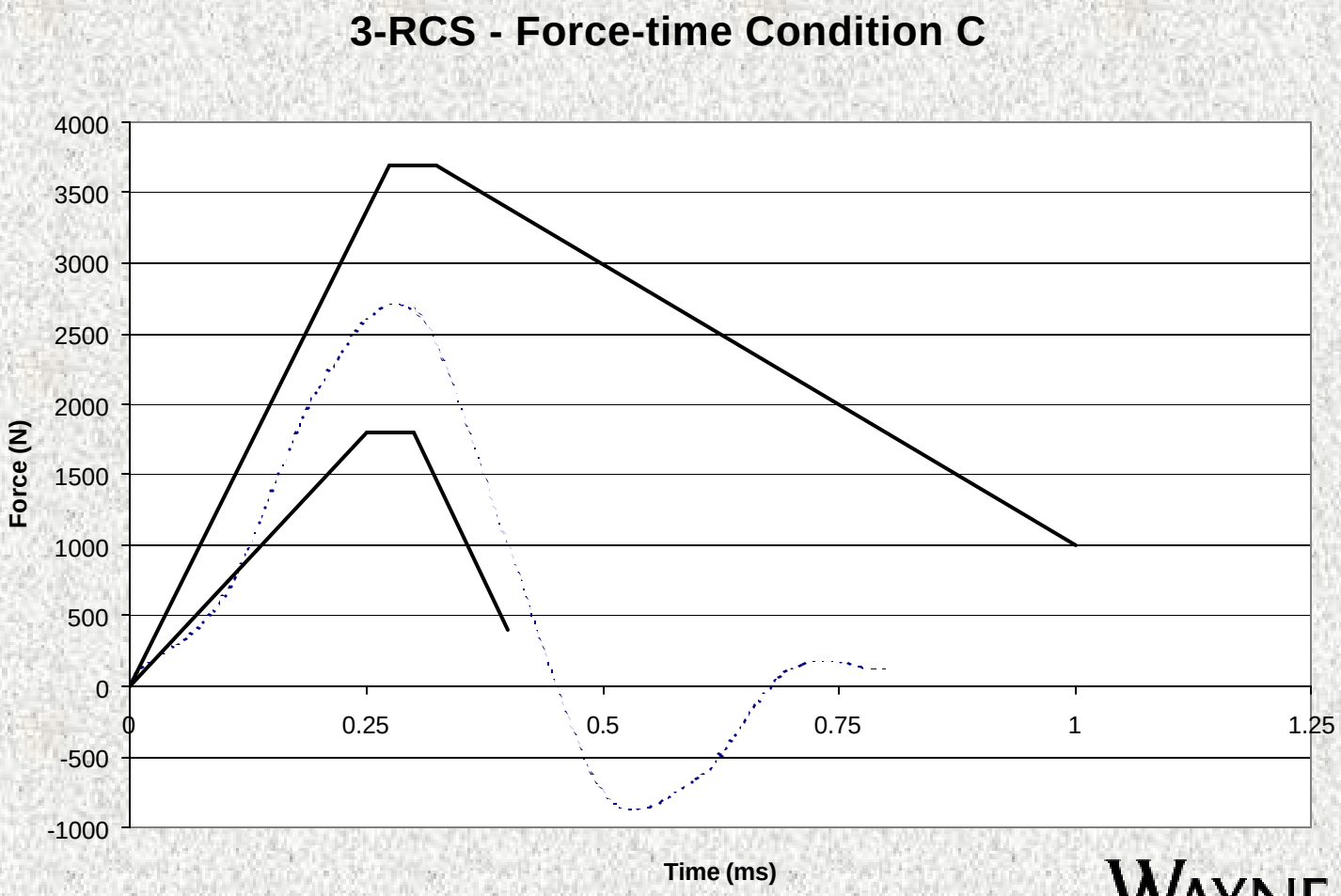
Revised 3-RCS - C Condition



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Conclusions

- Preliminary validation of a biomechanical surrogate, the 3-RCS, was conducted with further refinement proposed. The 3-RCS provides the ability to assess the continuous injury parameter of VC for predicting the risk of injury.

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Acknowledgement

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