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Characterizing Factors Associated with Thoracolumbar Fractures in Frontal Impacts

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CIREN: As Sentinel

Burst FX | Wedge FX | Minor FX

Outline

- Literature
- Quasi-static testing
- CIREN Case Histories
- Dynamic sled tests: First Series
- First tests series
- Vehicle test
- Computational Modeling
- Updated CIREN Case Histories
- Second sled test series
- Next steps?

Background: T-L FX in Crashes

- Univ of Washington – Seattle Study
  - NASS data 1993-2011
  - CIREN cases 1996-2012
  - 132 raw NASS cases ; 800 weighted cases where major compression lumbar spine fractures were sustained
  - Included horizontal and non-horizontal impacts:
  - 44% of the highest ranked severity events were horizontal frontal impacts
  - In vehicle MY 2000+ frontal impacts there were 2.5 times major compression lumbar spine fractures were sustained compared to vehicles older than MY 2000
  - In frontal crashes belted occupants: 5x greater odds of fracture than occupants not wearing a belt
  - Age also greatly increased the odds

Burst Fractures of the Lumbar Spine in Frontal Crashes, Kaufman, R.P., Ching, R.P.,Willis, M.M., Mack, C.D., Gross, J.A., Bulger, E.M., *Accident Analysis and Prevention (2013),*

Background: T-L FX in Crashes

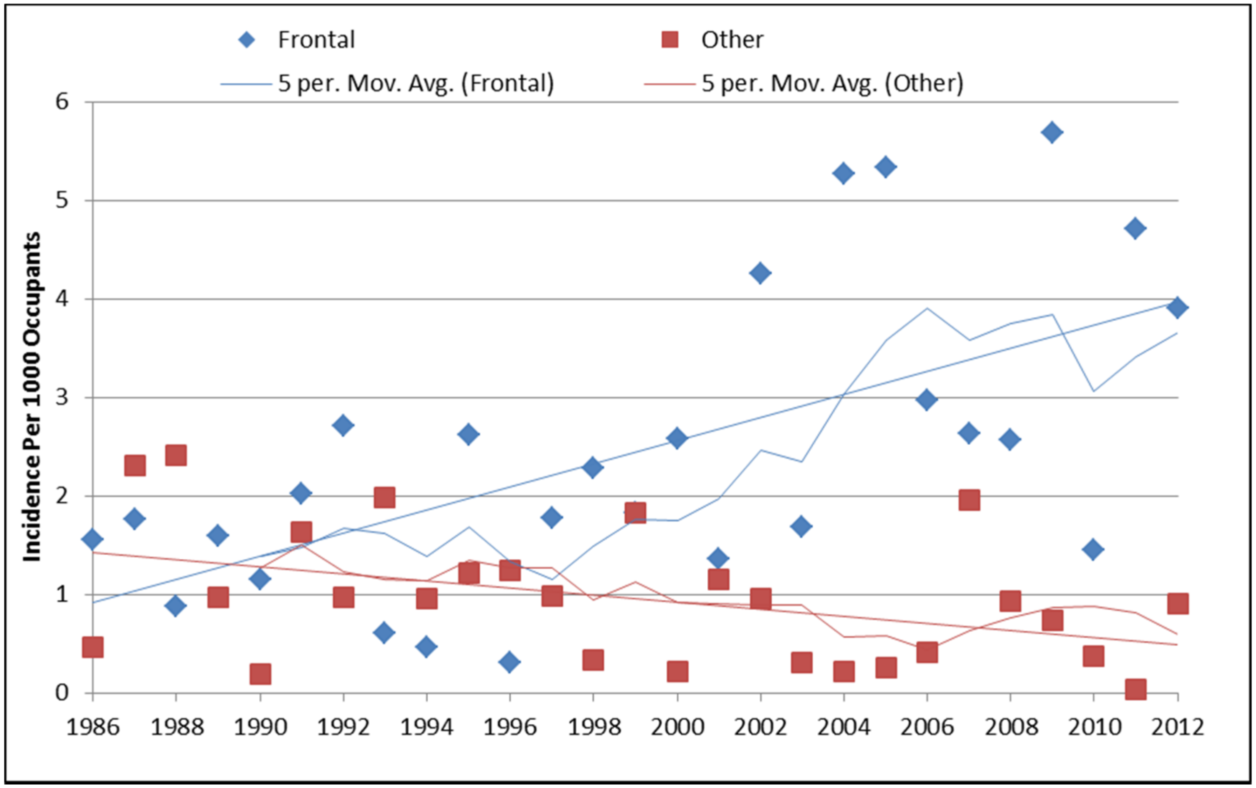
- Wake Forest Univ Study 2014
  - AIS or ICD-9 codes identify TL FX in MVC
  - National Trauma Databank1 (NTDB1) 2002–2006
  - National Automotive Sampling System (NASS) 2000–2011
  - National Inpatient Sample (NIS) 1998–2007
  - All databases showed increased MVC-related TL spine injuries
  - 8-10% relative annual increased incidence rate AIS2+ TL FX
  - ICD-9-codes identified 10,533 injuries in 2002 to 15,958 in 2006
  - Rising trend in TL injuries maybe result of a ‘trade-off’

Has the Incidence of Thoracolumbar Spine Injuries Increased in the United States From 1998 to 2011? Andrea N. Doud MD, Ashley A. Weaver PhD, Jennifer W. Talton MS, Ryan T. Barnard MS, J. Wayne Meredith MD, Joel D. Stitzel PhD, Preston Miller MD, Anna N. Miller MD, The Association of Bone and Joint Surgeons 2014

Background: T-L FX in Crashes

- MCW studies 2012 & 2014
  - NASS & CIREN databases
  - Increase T-L-spine FX in frontal impacts by vehicle MY

Statistically significant increased risk T-L-spine FX in newer vehicles: OR of 1.55



Thoracolumbar Spine Fractures in Frontal Impact Crashes, Frank A. Pintar, Narayan Yoganandan, Dennis J. Maiman, Mark Scarboro; Annual Proceeding of the Association for the Advancement of Automotive Med cine 2006; 50: 125–139.

Background: T-L FX in Crashes

- MCW Analysis
  - Omitted impacts where non-horizontal loads may have been a factor
    - Impacts half on road and half off the road
    - T- & L-spine body FX most common at T12 and L1 level.
    - AIS3, burst FX occurred predominantly at T12, L1 or L5;
    - Wedge fractures were most common at L1.
    - Object struck seemed to influence fractured spine level
- Working Hypotheses :
  - The crash shape of deceleration pulse may be an influence
  - Compression vector migrates up spine due to seat pan loading

Thoracolumbar Spine Fractures in Frontal Impact Crashes, Frank A. Pintar, Narayan Yoganandan, Dennis J. Maiman, Mark Scarboro; Annual Proceeding of the Association for the Advancement of Automotive Medicine 2006; 50: 125–139.

Findings by MCW 2014

- 86,176 weighted occupants met selection criteria and sustained T- & L-spine FX
- (612 raw occupants)
- 78% were involved in frontal crashes as the most severe event
- Compared vehicle cohort MY 2000-2012 with MY 1990-1999:
- There is increased risk of T- & L-spine FX in newer vehicles; with an OR of 1.55
- Of all occupants from 2009-2012 with a T- & L-spine FX the distribution of AIS 2+ injury to other body regions was:
  - **18% were associated with head injury**
  - **20% with thorax injury**
  - **7% with abdomen injury**
  - **4% with pelvis injury**
  - **7% with upper extremity injury**
  - **8% with lower extremity injury**

Findings by MCW 2014

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- The trend in the increase T-& L-spine fracture in planar frontal impacts reported by MCW in 2012 is actual
- The rate of the increase in its incidence merits attention
- The significance of the trend is substantiated by WF findings in data from:
  - The National Trauma Databank1 (NTDB1)
  - National Inpatient Sample (NIS), 1998–2007

If the rate of the increase in incidence treated is as analogous to simple interest:

15,958 weighted occupants[1] *8.59% age adjusted relative annual increase *14 years [2] = By 2020 35,149 weighted occupants [3]

[1] WF ICD-9 injures 2006 [2] Projected to 2020 [3] 2006 'plus interest'

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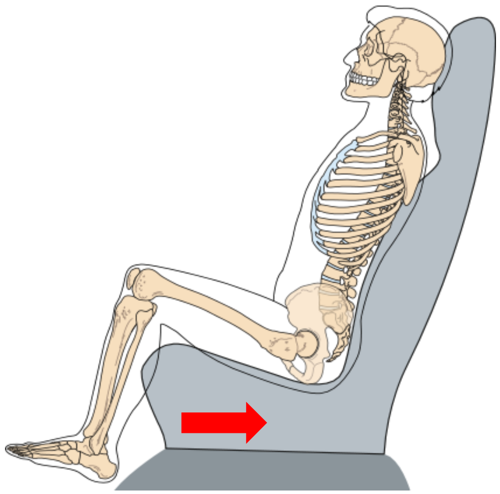
Review of WICIRENs Approach

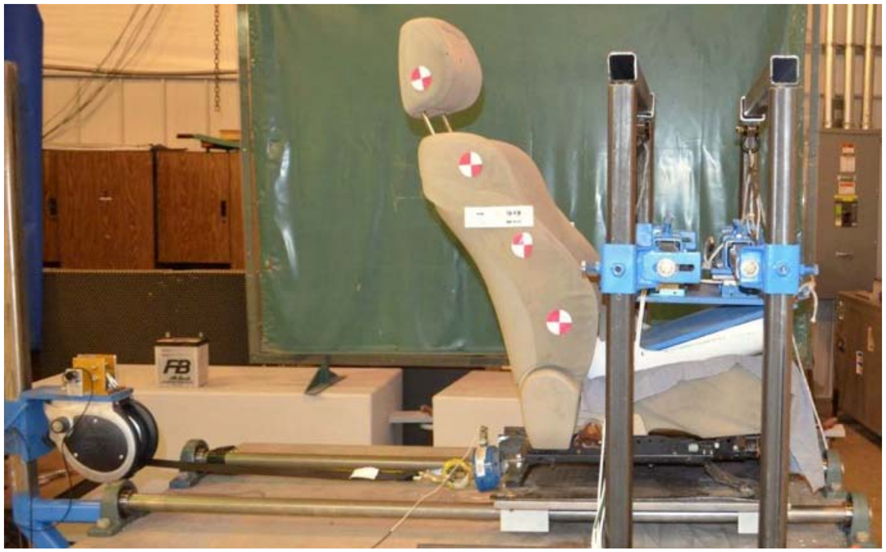
Initially we questioned whether the construction of the seat pan contributes to the incidence of T- & L-spine FX

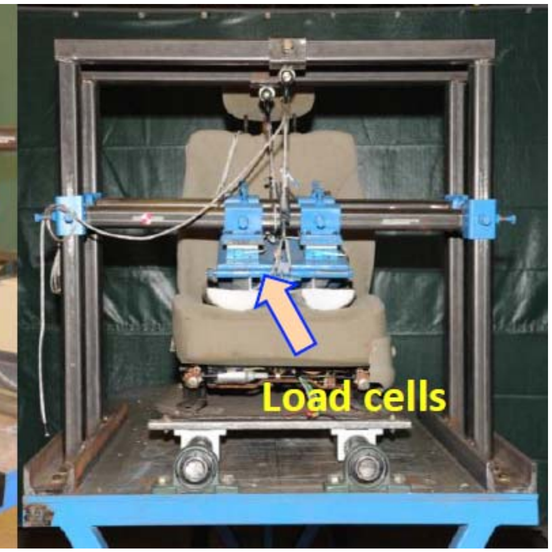


A seat testing apparatus was designed and evaluated to determine the static stiffness of any vehicle seat when it was loaded in a forward direction

Quasi-static Evaluation: Seat-pan “Stiffness”

Medical College of Wisconsin





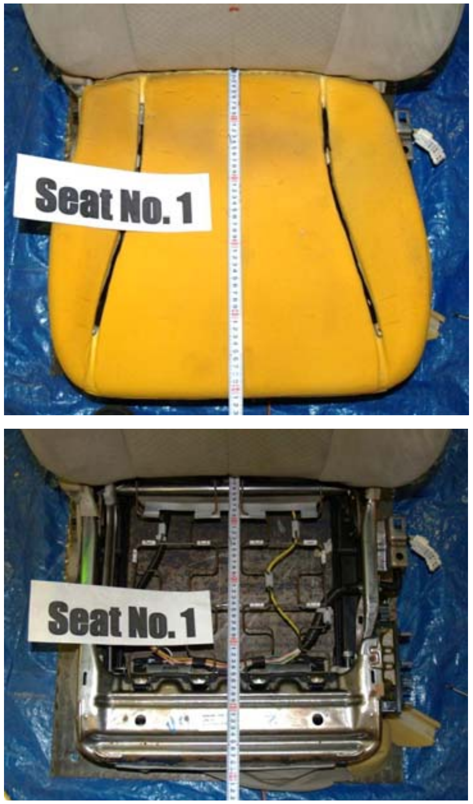
The device used an appropriately pre-weighted seat form to load the vehicle seat and moved the seat form forward relative to the seat cushion

Maximum vertical loadings from 5 models varied from 1082 N to 5655 N

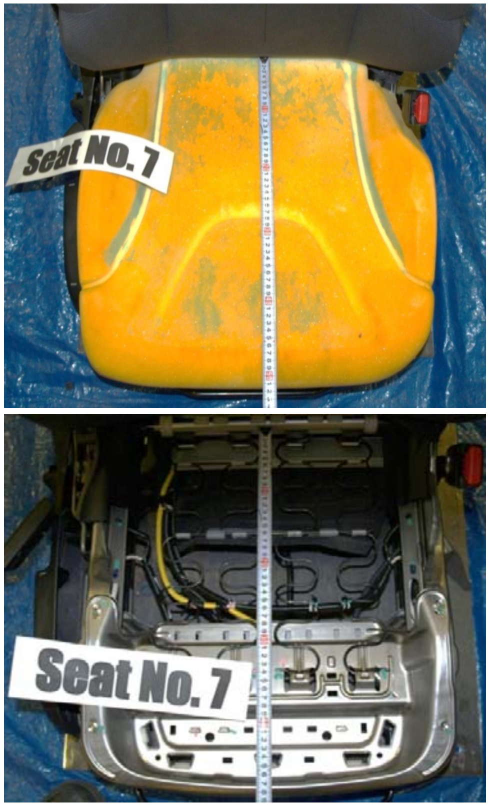
After disassembly, structural differences were found between the tested seat models that could account for the difference in seat reaction loads.

Evaluation of Seat-pan “Stiffness”

- The device permitted the classification of seats as either Stiffer or Tractable
- But the classification was not predictive of seat stiffness in dynamic testing
- Post-test disassembly revealed a range of seat designs



‘Stiffer’ Seat



‘Tractable’ Seat

Toyota Seat with Air bag in Cushion

Deployment tied seems to knee bolster air bag deployment

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Examination of CIREN Cases

Query Results for cases containing AIS codes for T- & L-spine body FX provided by NHTSA-CIREN

- Omitted impacts where non-horizontal loads may have been a factor:
    - 48/73 (66%) planar impacts
    - 35 on road; 38 off road
    - 30/73 (43%) tree/pole impacts
    - 37 one-rail; 25 zero-rail engagement
    - 11 two-rail (15%)
    - 70% below 56 km/h
    - Occupants
        - 90% belted
        - 55% female; 45% male

Results appear consistent with the working hypotheses

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Dynamic Sled Test Rationale: First Series

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- Replicate planar impacts i.e. no additional vertical component
  - o Belted occupant
  - o Nominal seat position
- ATD: Hybrid-III with straight lumbar spine
- Differences by seat type classification: Stiff vs. Tractable seats
- Selected OEM seats
- Different crash pulses
- Full frontal (two-rails engage)
  - o Pulse = NHTSA NCAP Full Frontal
- Pole frontal (zero-rails engage)
  - o Pulse = Average of IIHS Frontal Pole

Dynamic Sled Testing: Generic Pulses and ATD

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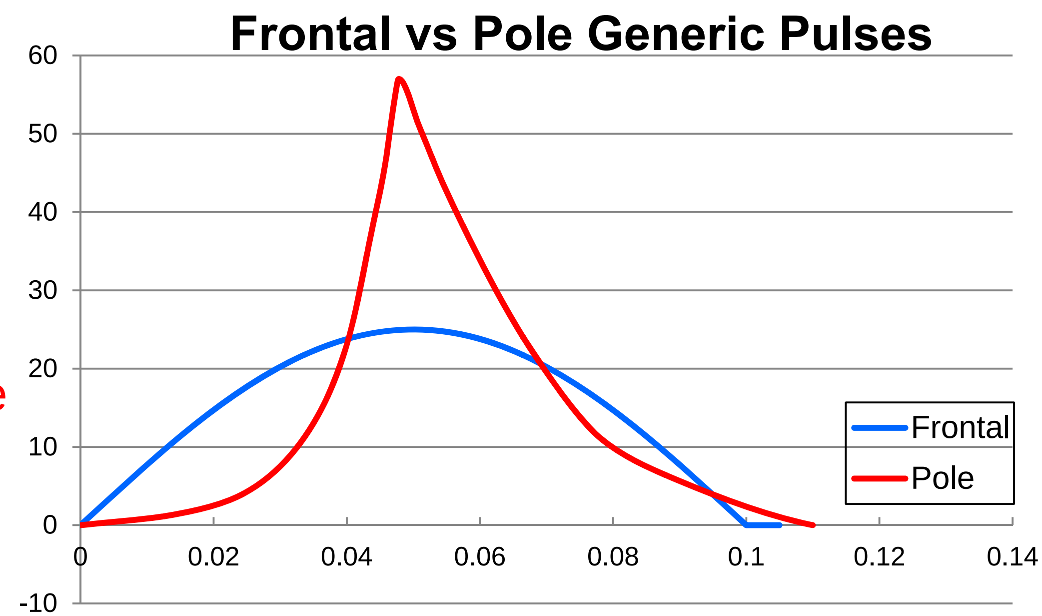
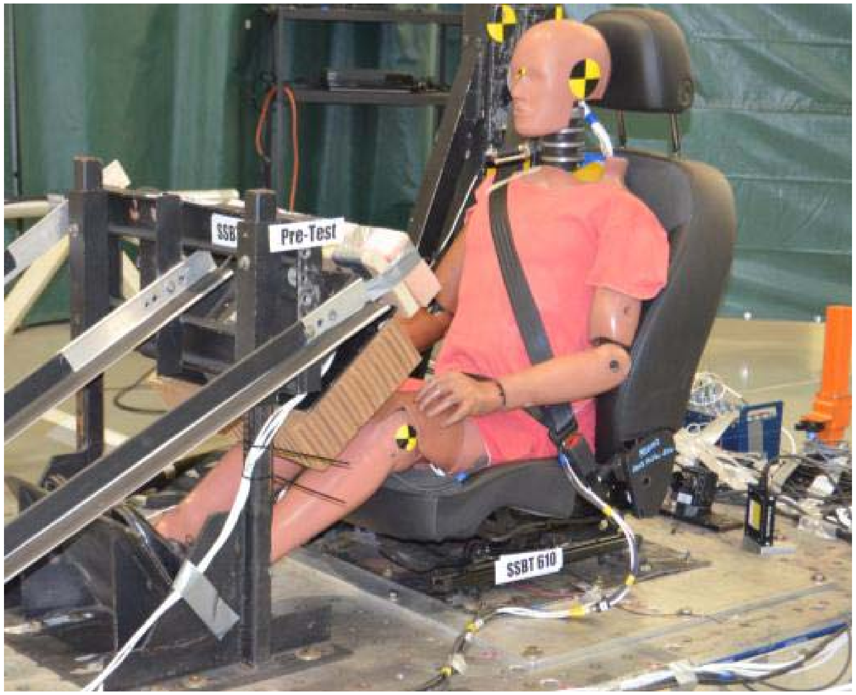
Full Frontal
– Sine pulse from NCAP testing
56 km/h
25 G’s
100 ms

Frontal Centered-pole Impact Pulse
From IIHS tests run at 64 km/h
Scaled to 56 km/h
55 G’s
110 ms



Dynamic Sled Testing: ATD Spine, Seats and Set-up

- FAA lumbar spine used
- OEM Seats – Selection based on quasi-static tests
- Dummy placement followed frontal NCAP procedures
- Knee Bolster angle adjusted to match tibia angle
- Knee distance 145 mm + 12 mm from bolster



Questions Addressed

- Does dummy differentiate between seats?
  - Yes but not same results as quasi-static
- Does crash pulse play a role?
  - Yes frontal pole pulse more severe
- Does belt interaction play a role?
  - Maybe Max belt load not coincident w/ max L-spine load

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Vehicle Crash Test

- Full-frontal vehicle crash 56 km/h
- 2001 Chevy Cavalier
- Standard 3-point belts, frontal airbags

Frontal Crash

Vehicle Test – 2001 Chevrolet Cavalier

The body seems to be pitching within the first 80ms of the event. This seems to account for the deformation of the still in the center and left images

At greatest engagement with SW assembly via AB.

When head begins to rotate indicating onset of rebound, shoulder is at its nadir relative to belt-line

Data showed the greatest z-load observed in the L-spine occurred after the peak change in in vehicle acceleration

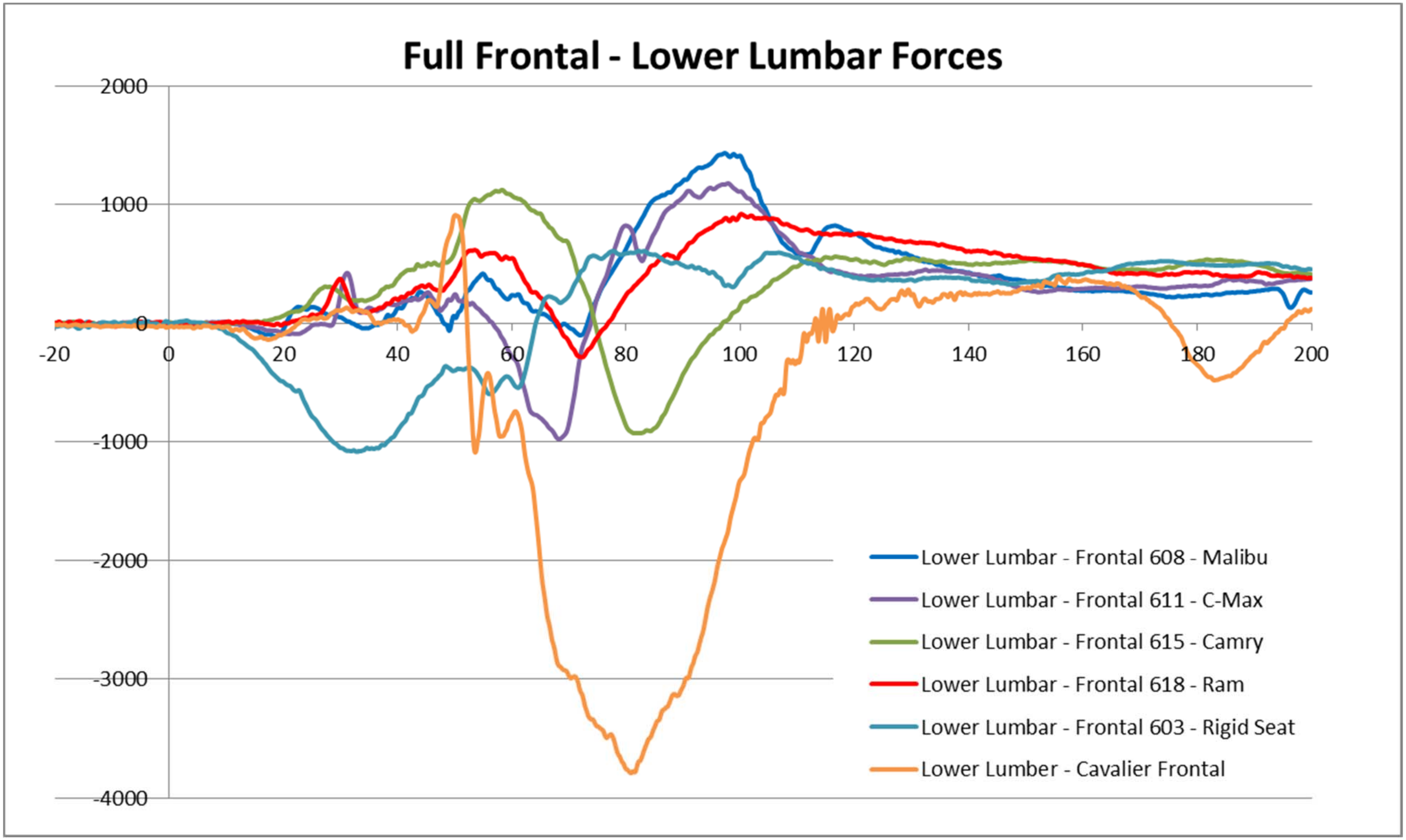
Post Test Assessment

- Seat deformed substantially

LF

RF

Dummy Lumbar Spine Forces



Sled and Vehicle Test Results & Outcome

- Lumbar spine compression occurs in planar impacts
- Seats classed as "Stiff" in static tests did not produce the maximum compressive loads in dynamic tests
- Maximum belt loads generally precede maximum lumbar loads
- Peak lumbar compressive forces generally greater for frontal pole pulse
- Peak lumbar loads not time coincident with belt or femur loads
- Greater excursion in vehicle test likely produced greater lumbar loads – What are relevant factors - parametric study?

These results prompted an investigation using FEM modeling to determine what may be critical factors

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Computational Modeling

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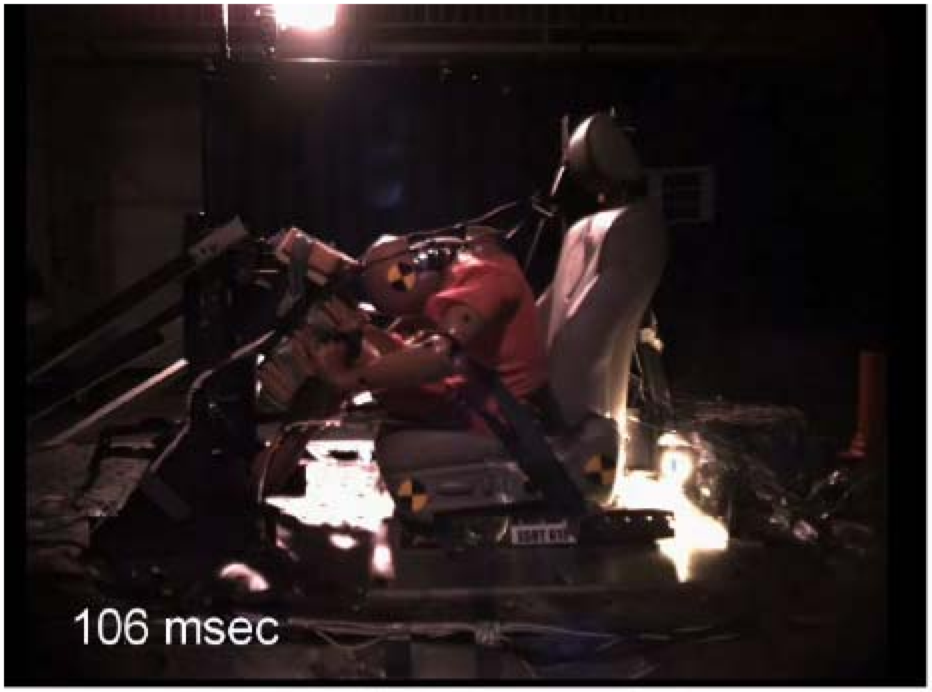
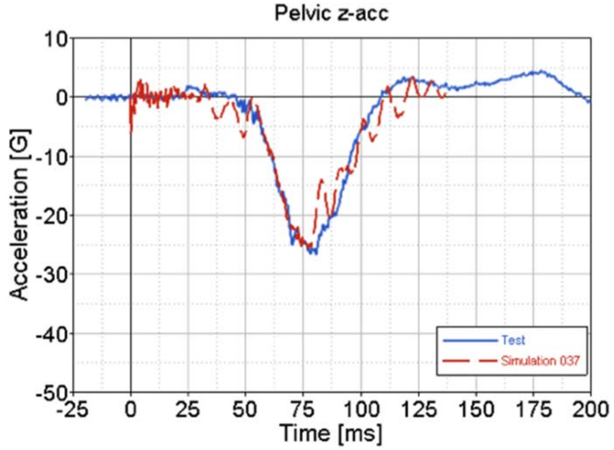


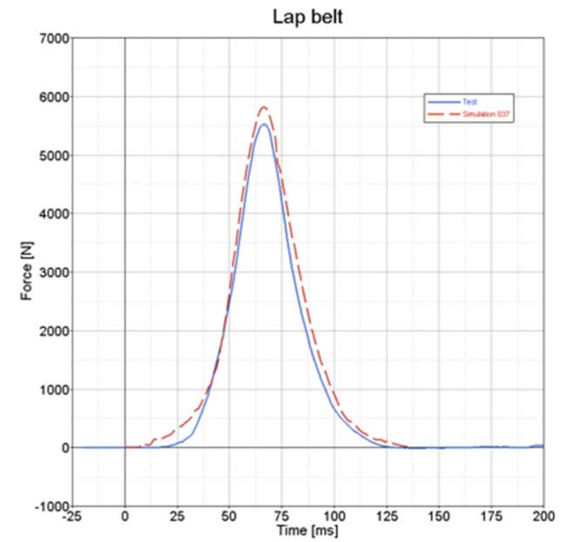
Johan Iraeus and Prof. Mats Lindkvist of Umeå University

- Created a generic seat structure FE model with H3 dummy
- Static validation against MCW static seat stiffness tests
- Dynamic validation against MCW sled testing

Computational Modeling

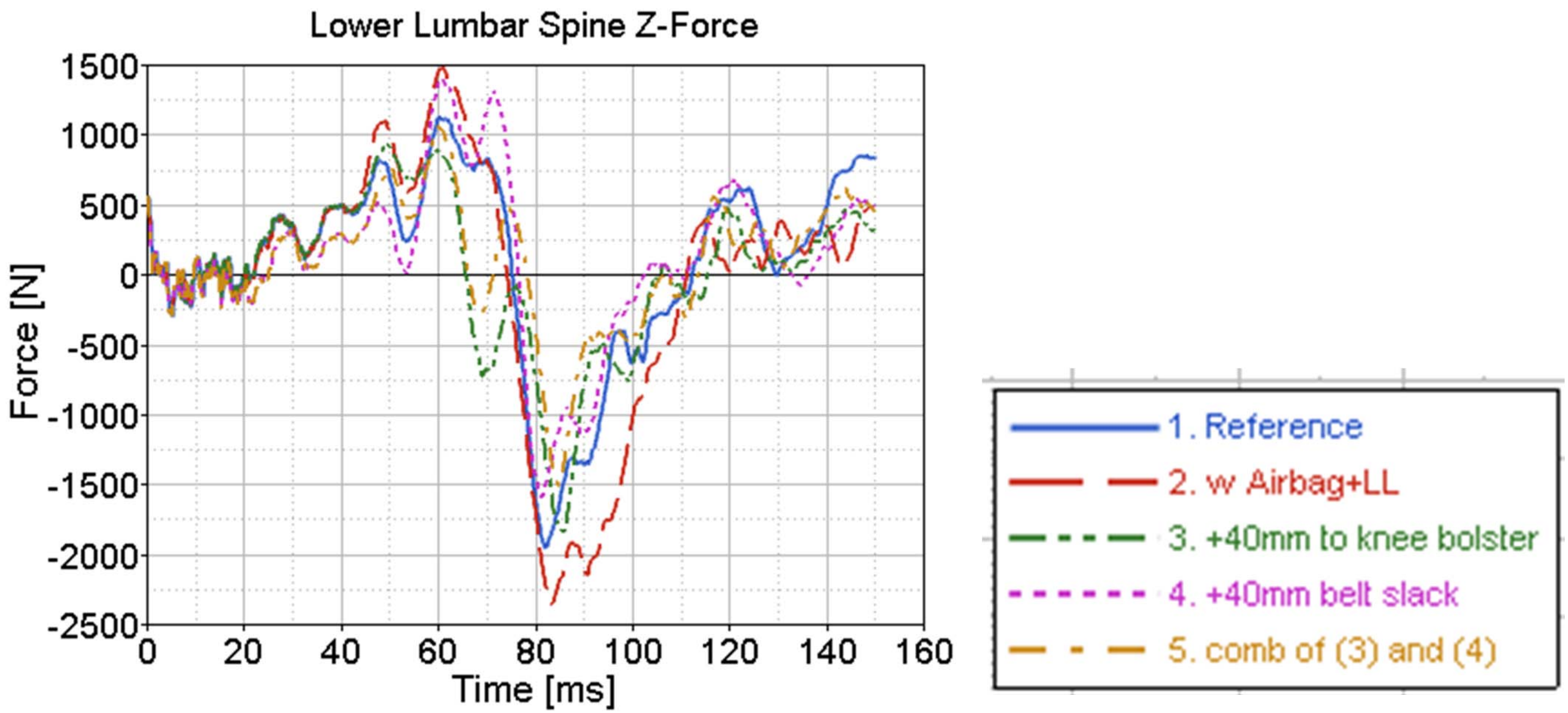
- Validation resulted in good match with kinematics and belt loads
- Lumbar spine loads *in model a little higher than in sled* experiments
- Conduct parametric study
  - Effect of pulse
  - Effect of belt restraint slack
  - Effect of knee bolster distance
  - Effect of Airbag & Load limiter
  - *Maximize Lumbar Z-Loads*





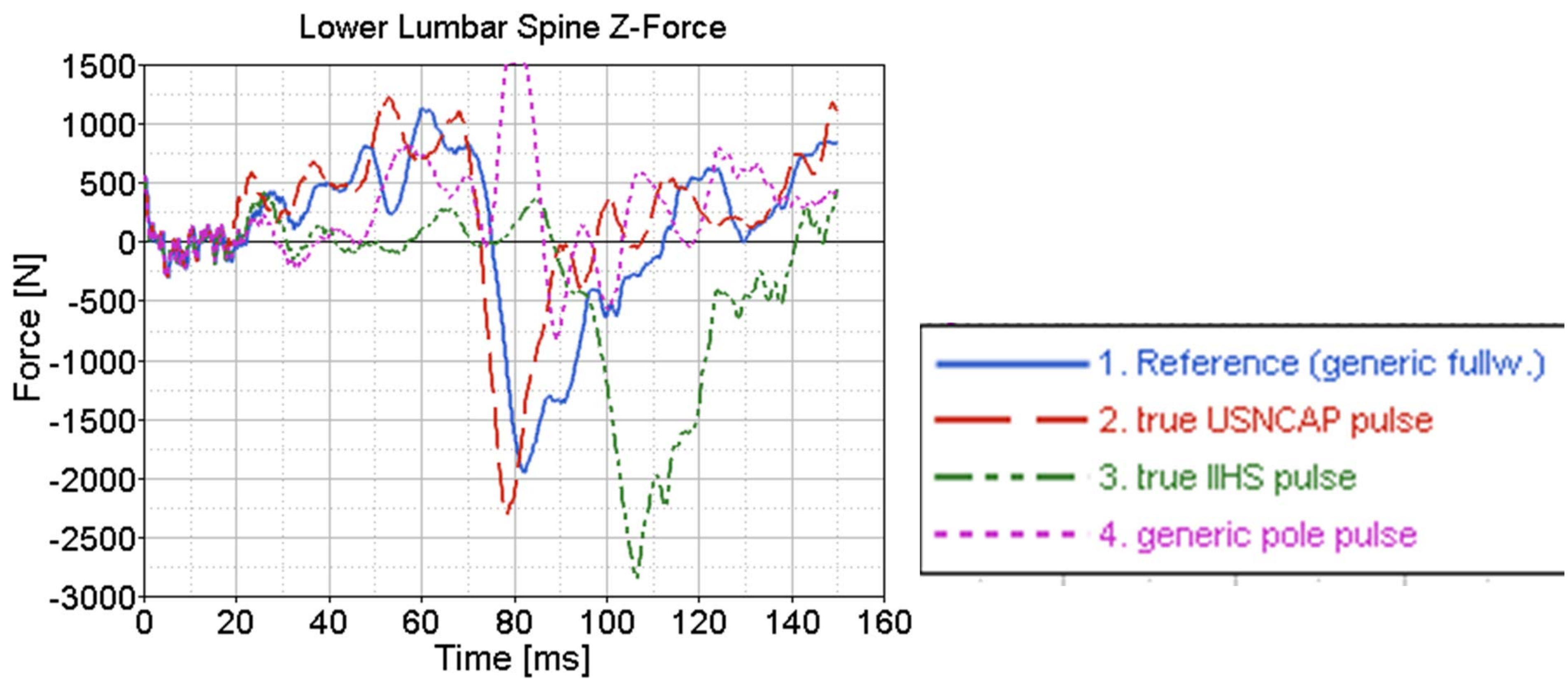
Computational Modeling Results

- Airbag & load limiter gave highest lumbar z-loads
- Belt slack or knee-to-knee bolster distance had small effect



Computational Modeling Results

- Effect of acceleration pulse:
  - IIHS 40% offset frontal pulse gave highest lumbar z-load
  - Generic MCW pole pulse gave lowest lumbar z-load



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Updated Analysis of CIREN Case Histories

- Previous analysis of CIREN case histories was updated

- Omitted impacts where non-horizontal loads may have been a factor

- Same selection criteria:
    - Model Year 2000+
    - Front seat occupants 16+ years
    - Spinal fracture T10 and below
    - Rollover/ejections excluded
    - Undercarriage engagement also excluded

Updated Analysis

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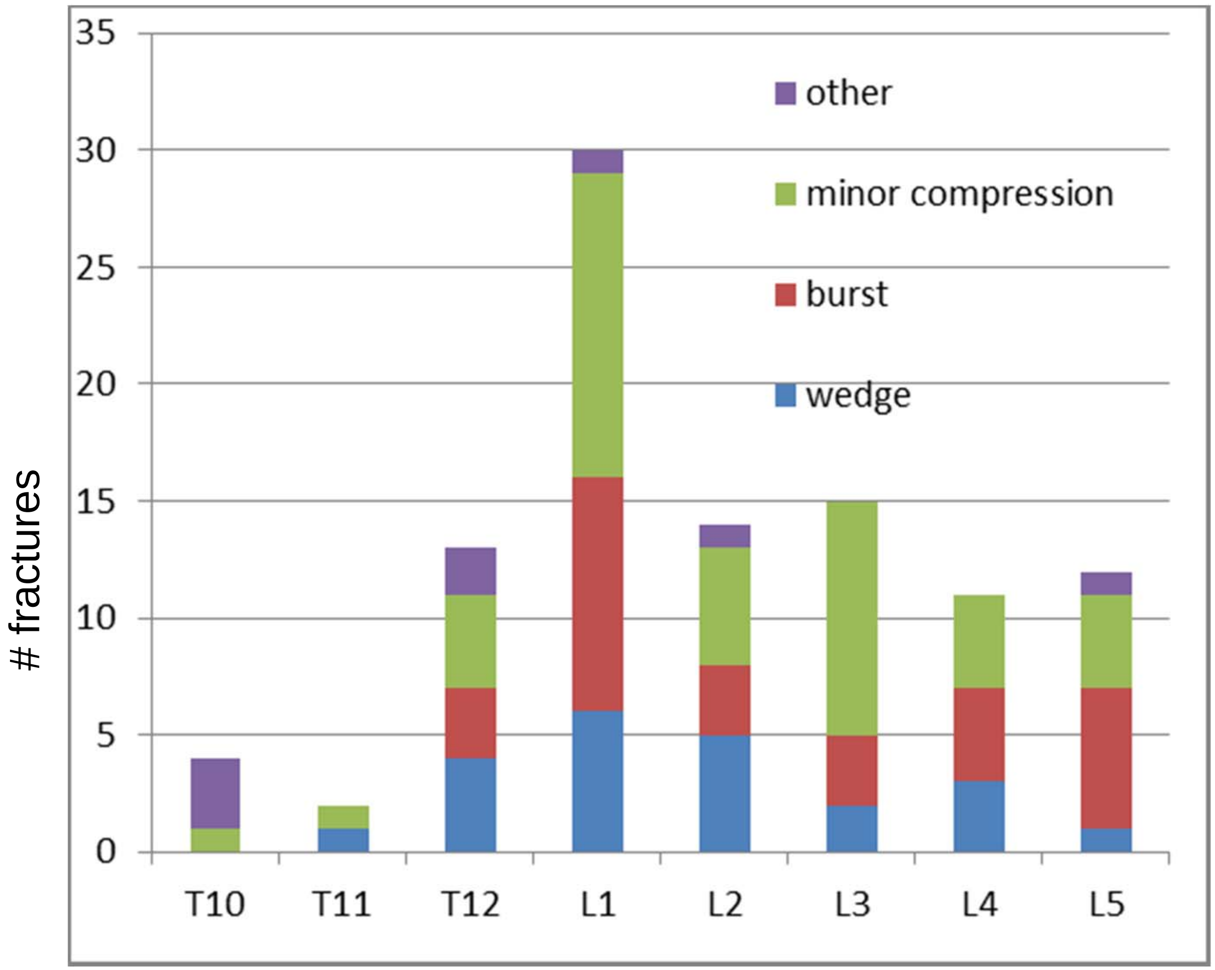
- 82 cases → 102 spinal fractures
  - ~1/2 single vehicle crashes
- L1 most common → 30 fractures (29%)
- T12 & L2-L5 → 65 fractures ~ evenly distributed by spine level
- Minor, burst and wedge fractures all more frequent @ L1 spinal level
- 50-59 YO group highest group (17/82)

Fracture Classification/location



Spinal level – AIS codes w/ Denis classification applied

Updated Analysis: DV and Engagement of Structure

- 64 cases (74%) BES<= 56 km/h → 67 injuries
  - 57 cases w/60 injuries graded as burst, minor compression or wedge fractures
  - Only 5 cases were similar to Frontal NCAP
  - 26 cases 1 structural member engaged
  - 18 cases no longitudinal member engaged
- Frontal NCAP/208 crash pulse may not replicate the type of loads observed by ‘real world’ occupants

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Dynamic Sled Testing: Series Two

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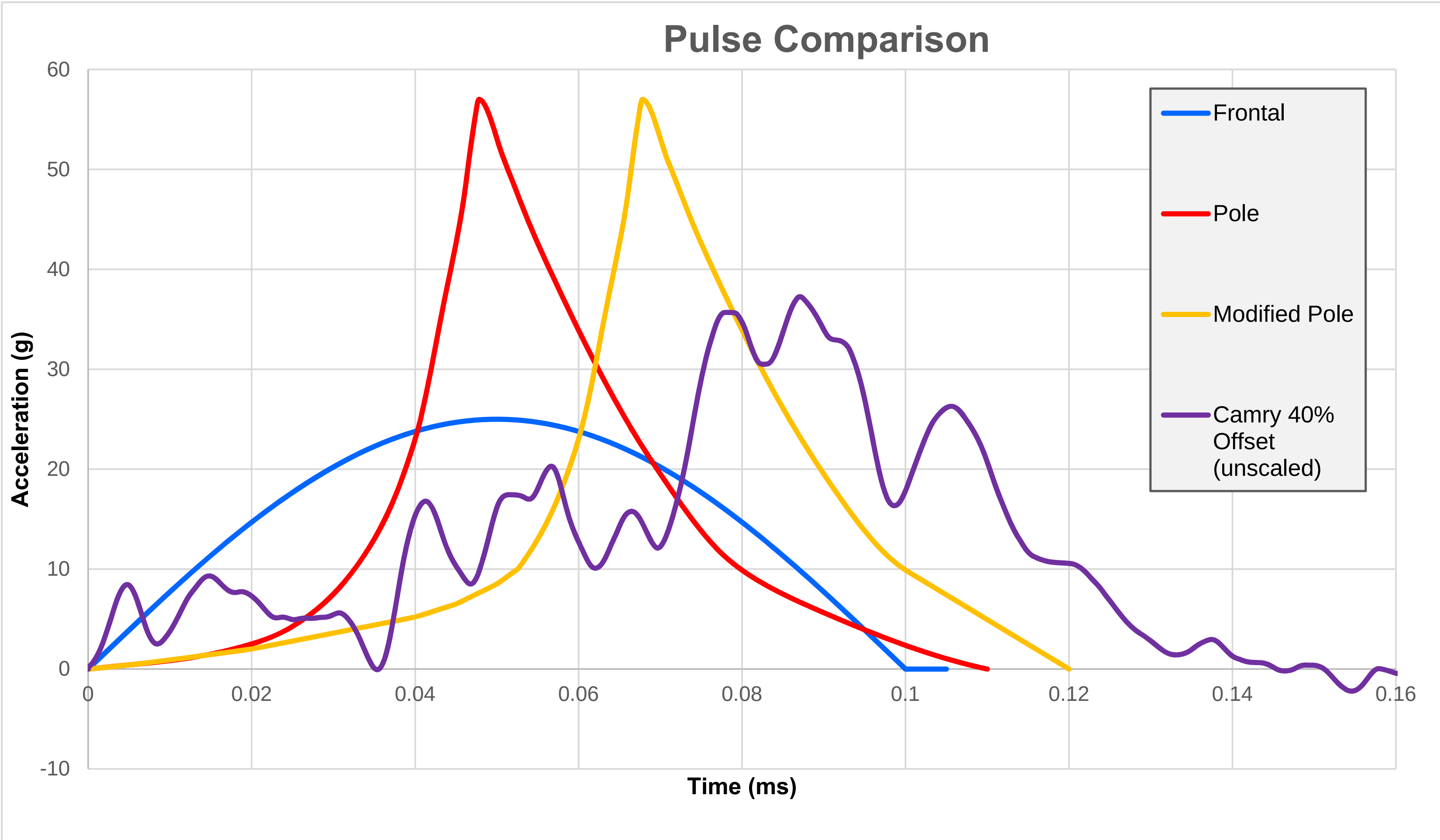
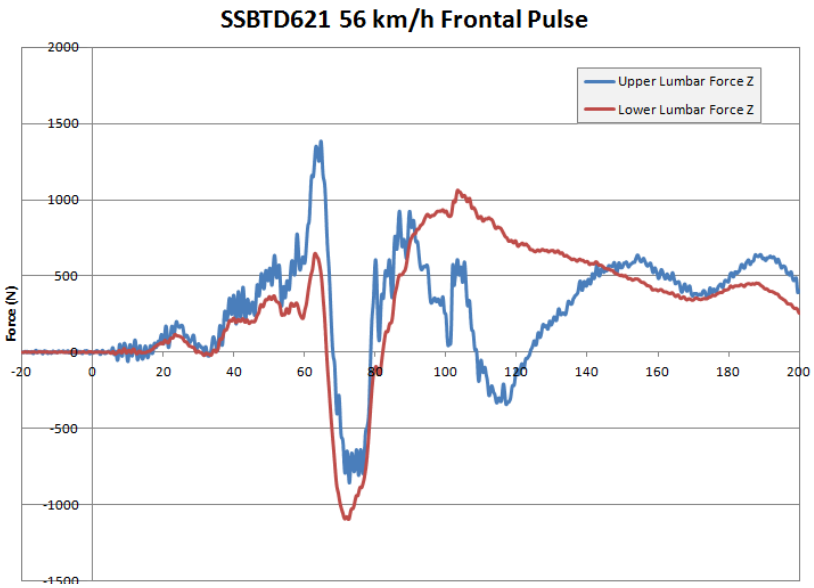
- Additional sled tests conducted with Toyota Camry seats
- Verify FE Model results:
  - 40mm belt ‘slack’ added to the 3-pt belt restraint
  - The knee–bolster 40mm larger gap to knees
- Sled tests conducted with above and pulses:
  - generic NCAP frontal
  - generic center-punch pole
  - 40% offset frontal IIHS from 2002 Toyota Camry
  - Modified (20ms shifted) center-punch pole

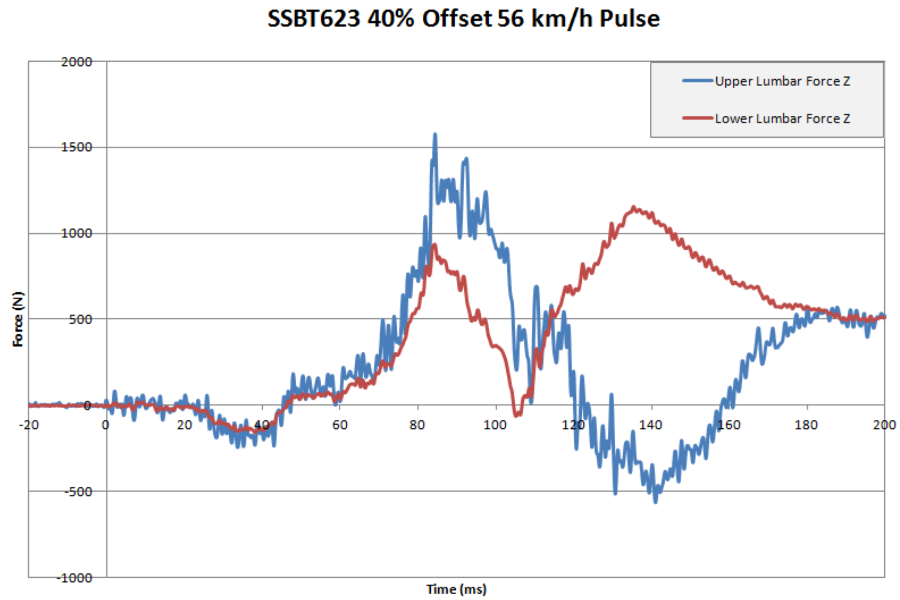
Dynamic Sled Testing: Series Two

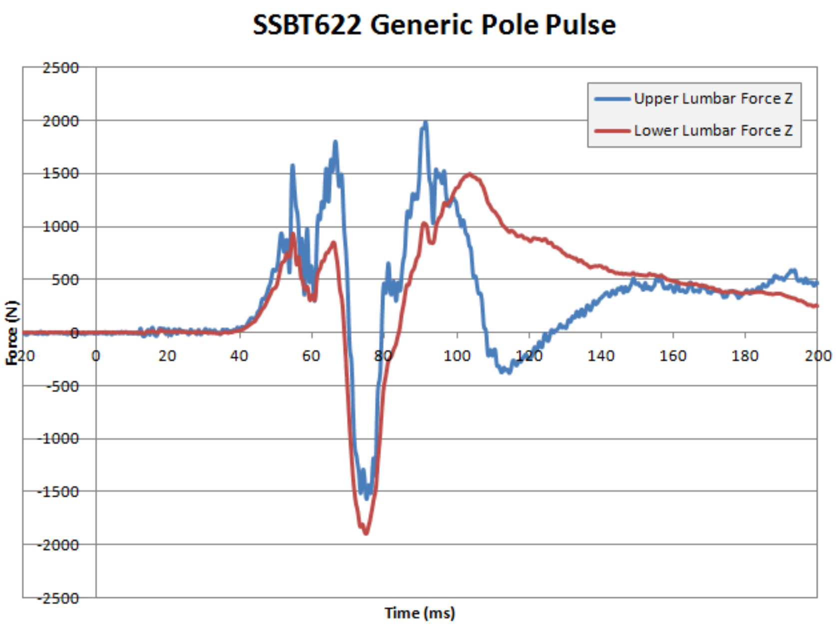
Dynamic Sled Testing Series Two: Pulses

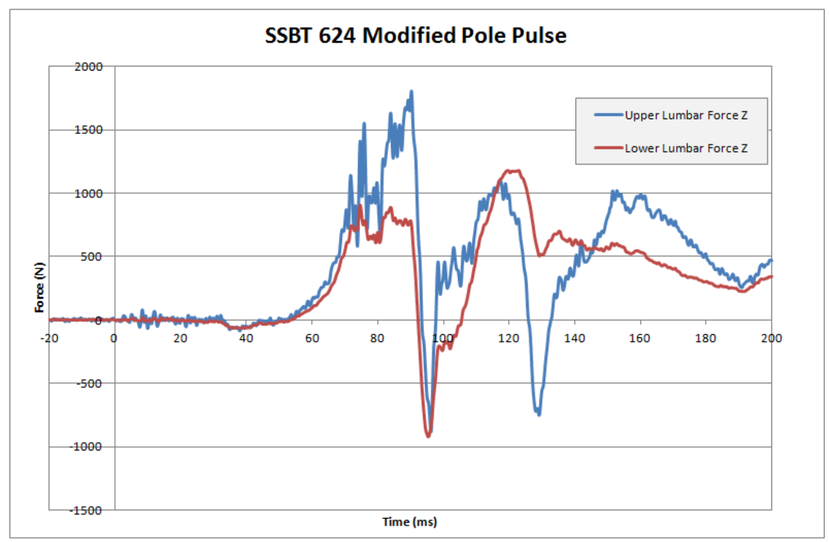


Dynamic Sled Testing Series Two: Results

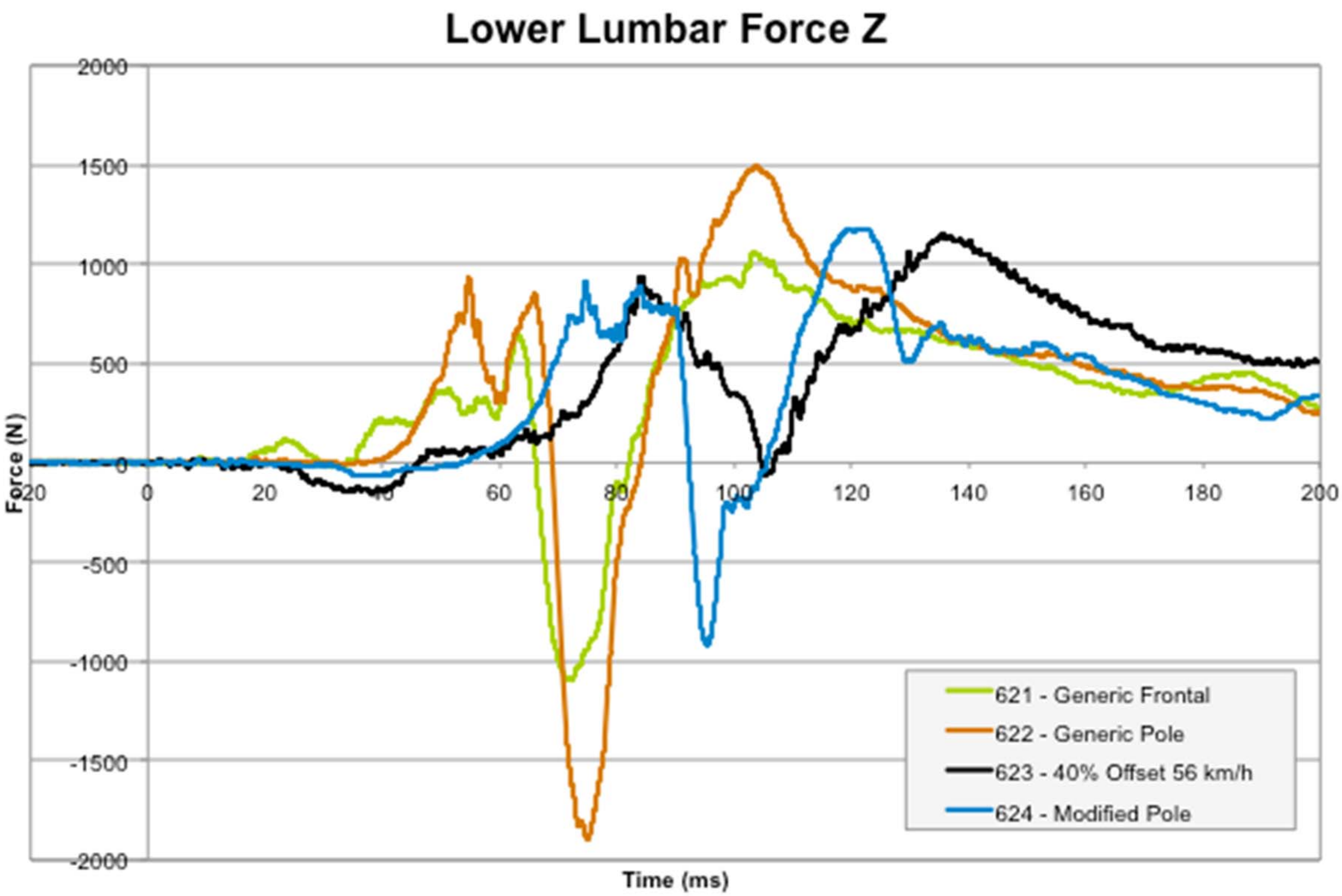








Dynamic Sled Testing Series Two: Results



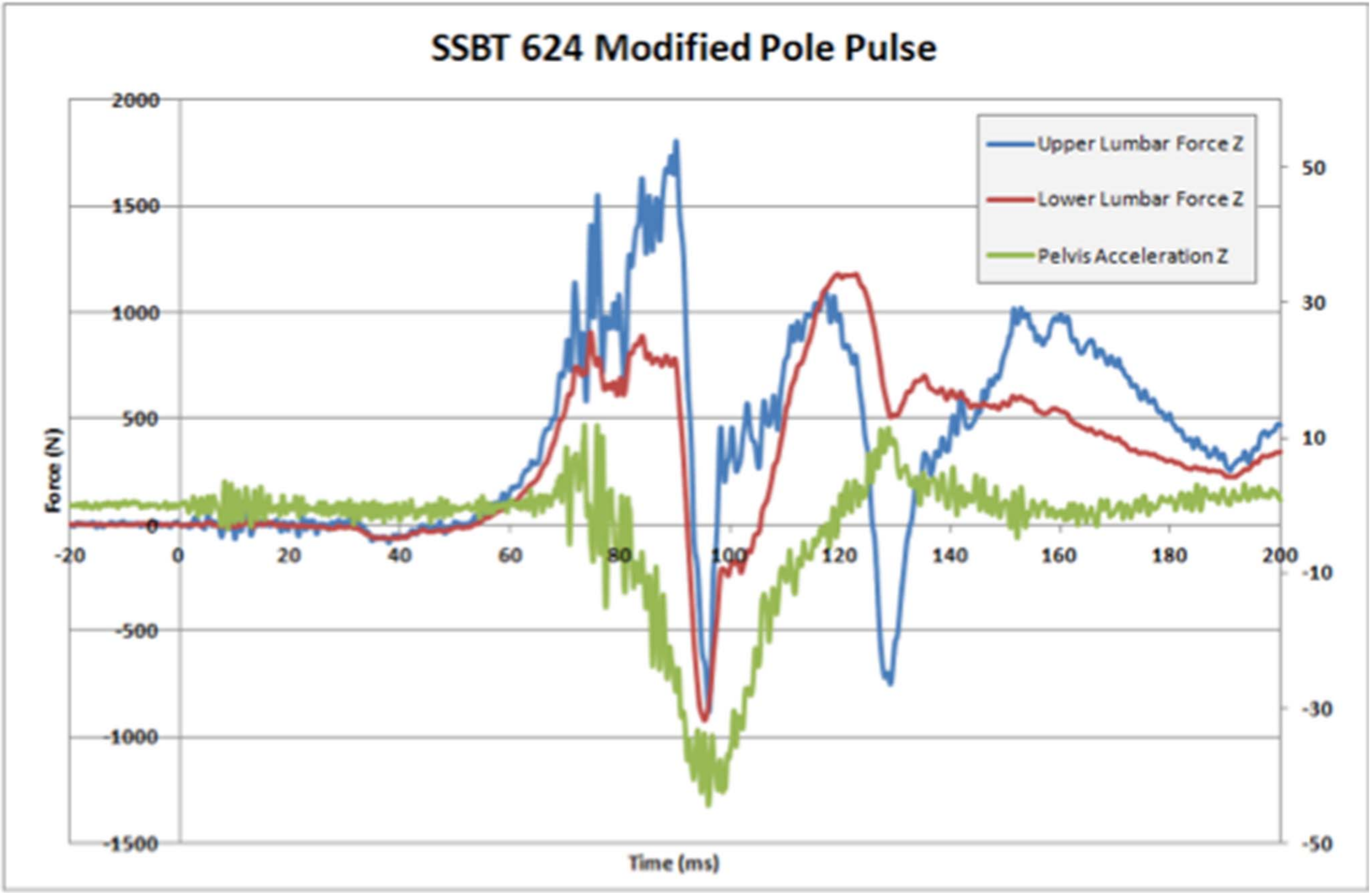
Dynamic Sled Testing Round 2: Results

Test Pulse	Upper Lumbar Force (N)	Lower Lumbar Force (N)
56 km/h Frontal	-854 @ 72 ms	-1089 @ 72ms
CEF 0202 40% off-set	-555 @ 141ms	-43 @ 105
Generic Pole Pulse	-1553 @ 75ms	-1805 @ 95ms
Modified Pole Pulse 1st Peak	-842@ 96ms	-909@ 95ms
Modified Pole Pulse 2nd Peak	-717 @ 128 ms	

Peak force on the pelvis is in phase with the lower lumbar forces in each test

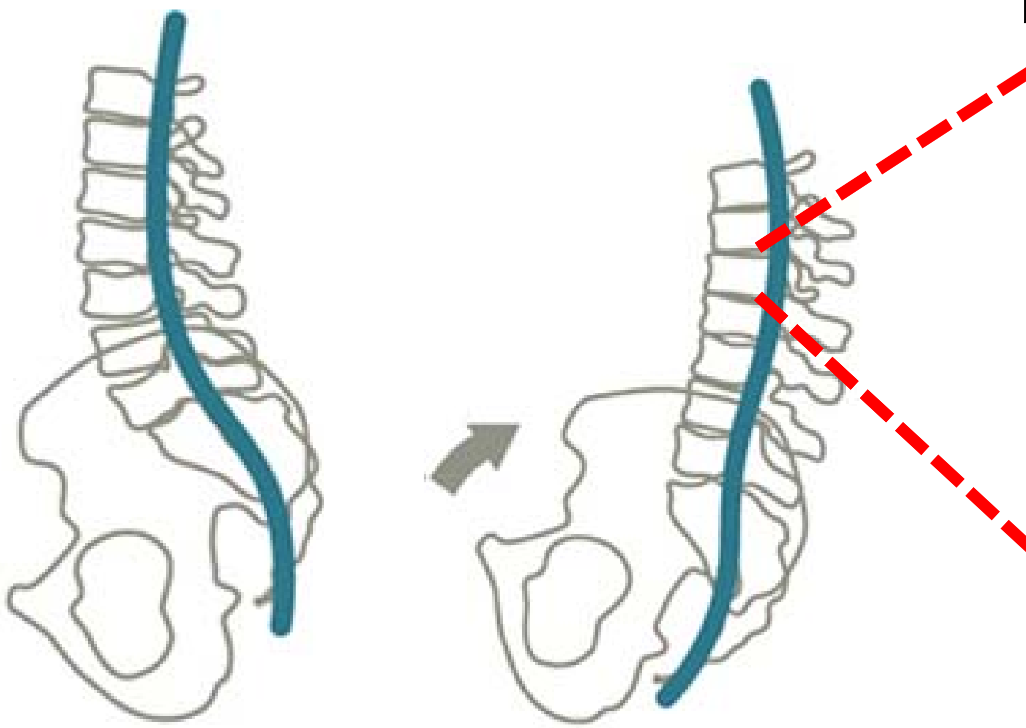
In the data for the modified pole pulse 2nd peak the 2nd negative peak in the upper lumbar force is in phase with a positive rise in the force on the pelvis

Dynamic Sled Testing Round 2: Results

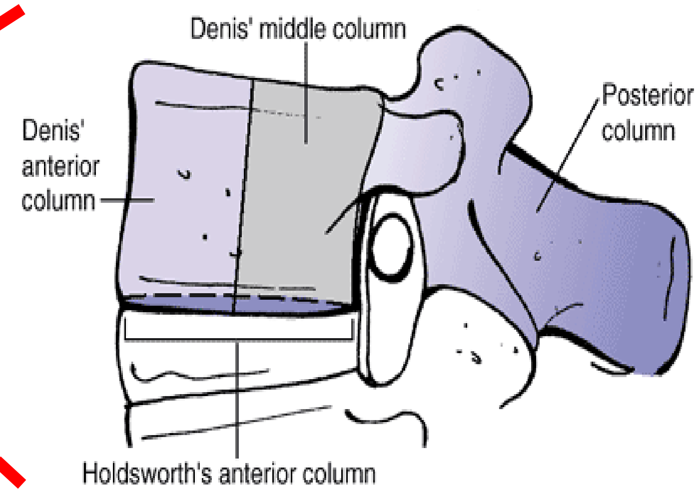


Refinement of Hypothesis

Sled tests, modeling and the crash test indicated a key factor in T- & L-spine FX may be the function of alignment of pelvis.



burst, wedge, minor compression



Summary & Conclusions

- The phenomena of increasing T- & L-spine fracture in planar frontal impacts is real
- The rate of the increase in the incidence of these injuries merits attention
- The injuries appear to be sustained late in the event
- The assumption the correlation between DV and injury will the prime predictor leading to a mechanism of injury may be too simple
- The seat belt in the role of a boundary condition for the mechanism of injury is in doubt
- The seat belt in the role of a factor influencing the position of the pelvis still seems supported
- The role of the knee bolster as a factor influencing the position of the pelvis/spine merits further investigation
- The validity of the generic FEM seat model is in question

Sled Testing: IIHS Frontal Pole Pulses