Driver Lower Extremity Response and Injury with Knee Airbag Deployment

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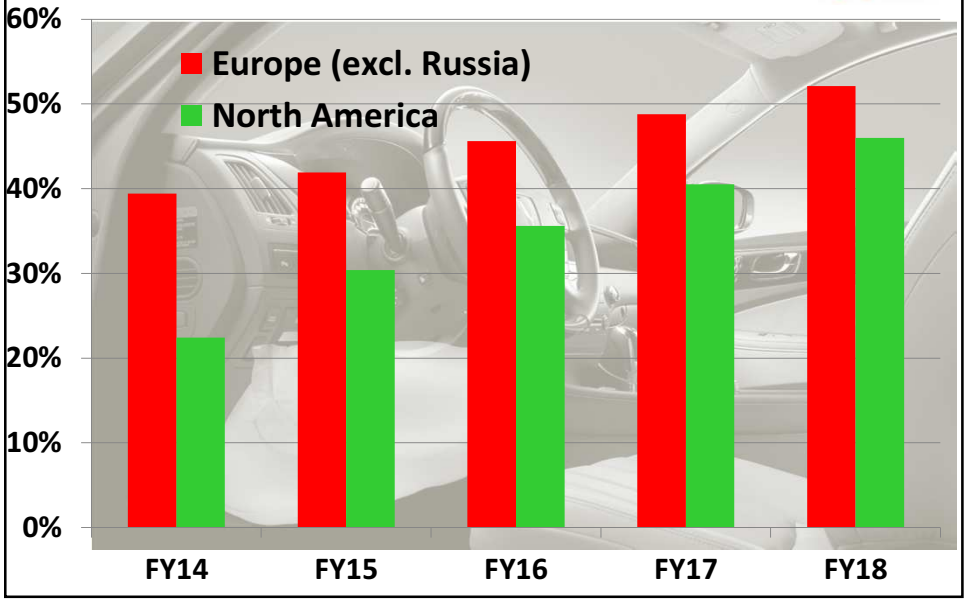
C Michetti, R Freeth, C Vo,
R. Rudd, M. Scarboro

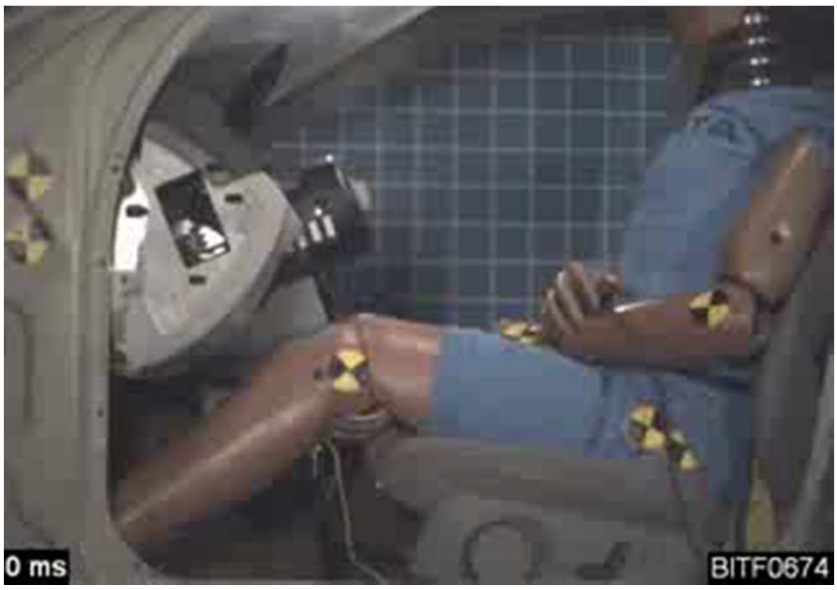
University of Virginia - INOVA Fairfax Hospital
CIREN Center

Driver KAB: Market Data Forecast

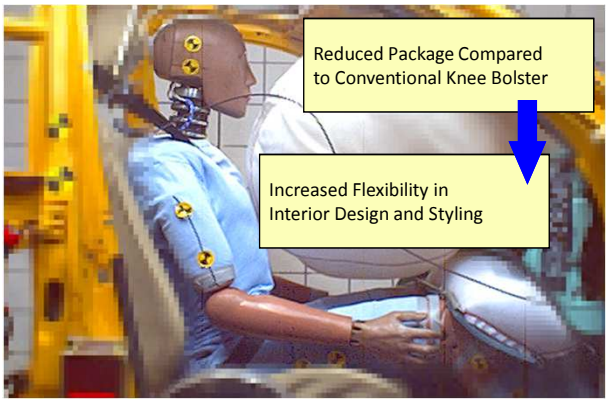
(First KAB: 1998 Kia Sportage)



Knee Airbag System



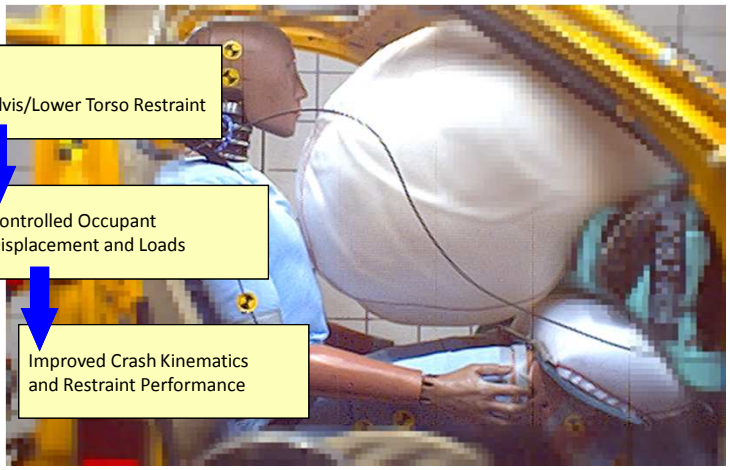
Knee Airbag System



Roychoudhury et al., 2004

Knee Airbag System

Objectives of a Knee Airbag system



Improved Occupant Safety and reduced Package

TRW, 2000

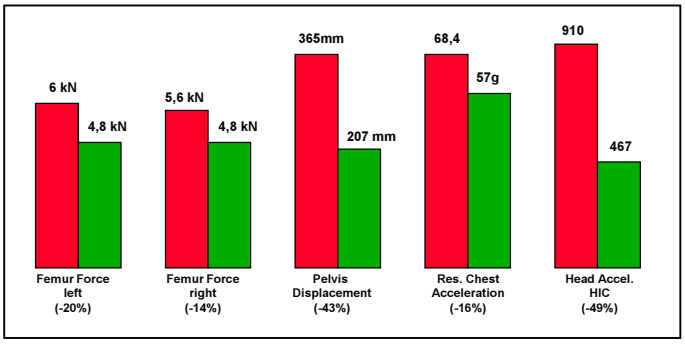
Knee Airbag:
Driver Side 48 km/h, unbelted

FMVSS208

50% HIII
30 mph, unbelted
(TA0179-V02 / V05)

Knee Bolster

Knee Airbag

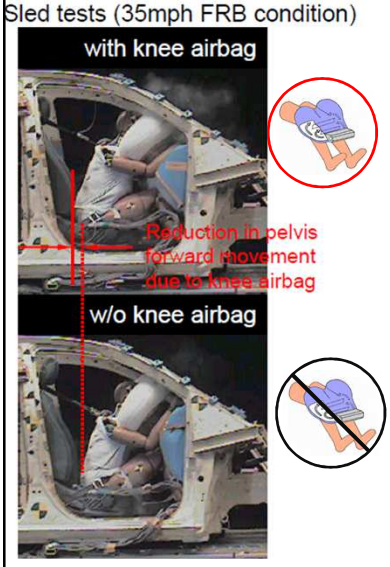


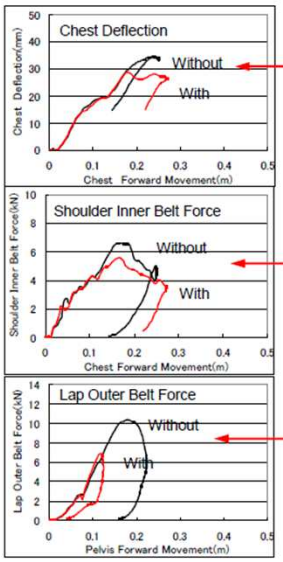
*) Reduced head acceleration: A heat contact to the wind screen was avoided because of an earlier beginning of chest rotation

TRW, 2000

Knee Airbag: Driver Side 56 km/h, belted

Sled tests (35mph FRB condition)





Since shoulder inner belt load decreases, chest deflection decreases.

Shoulder inner belt load is reduced so the load to chest is also reduced.

Knee airbag reduces the forward movement of the pelvis and the lap belt load into the abdomen.

ISO TC22 SC10 WG3 N292

KAB: Lower Extremity

- KAB reduce knee-thigh-hip loads
- KAB should reduce entrapment of knee, thereby reducing tibia/fibula forces with intrusion

Investigation of the Safety Effects of Knee Bolster Airbag Deployment in Similar Real-World Crash Comparisons

Weaver et al. (WFU CIREN), 2013

- CIREN KBAB cases (9) were compared to non-KBAB cases (22) of the same vehicle model using a similarity scoring algorithm
- Reduction in femur fractures was observed in KBAB occupants (p-value = 0.036) but increases in proximal tibia/fibula and foot/ankle fractures were observed in KBAB occupants (p-values = 0.022 and 0.002, respectively).

The association between knee airbag deployment and knee–thigh–hip fracture injury risk in motor vehicle collisions: A matched cohort study

Vijal Patel[a], Russell Griffin[a,c], Alan W. Eberhardt[b], Gerald McGwin Jr.[a,c,*]

[a] Center for Injury Sciences at UAB, Department of General Surgery, University of Alabama at Birmingham, Birmingham, AL, United States
[b] Department of Biomedical Engineering, University of Alabama at Birmingham, Birmingham, AL, United States
[c] Department of Epidemiology, University of Alabama at Birmingham, Birmingham, AL, United States

- CIREN and NASS (2000-2009) matched cohort study, front-seat occupants in frontal collision
- Occupants exposed to KAB were matched to occupants with no KAB based on age, sex, belt use, seating position, vehicle body type, collision impact, and sampling weight.

Risk ratios (RRs) and associated 95% confidence intervals (95% CI) for the association between knee airbag (KAB) deployment and risk of lower extremity fracture.

	KAB deployed (n = 277)	No KAB deployed[a] (n = 277)	cRR (95% CI)[b]	aRR (95% CI)[c]
Any lower extremity fracture	33 (11.9)	40 (14.4)	0.83 (0.52–1.31)	0.87 (0.51–1.4
Knee–thigh–hip fracture	18 (6.5)	26 (9.4)	0.69 (0.38–1.26)	0.71 (0.36–1.4
Hip fracture	11 (4.0)	13 (4.7)	0.85 (0.38–1.89)	0.72 (0.26–1.9
Thigh fracture	9 (3.2)	13 (4.7)	0.69 (0.30–1.62)	0.81 (0.32–2.0
Knee fracture	2 (0.7)	4 (1.4)	0.50 (0.09–2.73)	1.13 (0.13–9.6
Tibia/fibula fracture	15 (5.4)	14 (5.1)	1.07 (0.52–2.22)	1.23 (0.52–2.9
Foot fracture	14 (5.1)	11 (4.0)	1.27 (0.58–2.80)	1.96 (0.72–5.3

[a] No KAB deployed individuals matched to KAB deployed individuals by age ±5 years, sex, seatbelt use, seat position, vehicle body type, collision impact, and sampl weight ±1500.
[b] Based on Cox proportional hazards regression stratified by matched set.
[c] Adjusted for height.

Accident Analysis and Prevention (2013

Leg Injury Hypotheses - KAB

1. KAB causes injuries in Out-of-Position scenarios.

EVALUATION OF THE RISK OF INJURY CAUSED BY A KNEE AIRBAG IN OUT-OF-POSITION

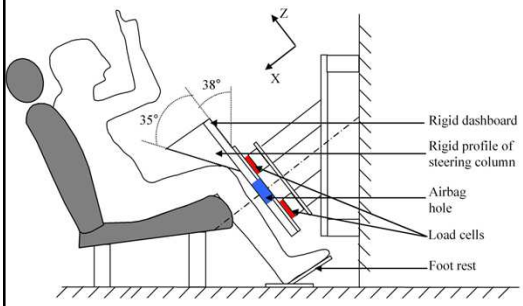
Tiphaine Leport, Pascal Baudrit,
CEESAR, France
Philippe Petit, Xavier Trosseille,
LAB PSA Peugeot Citroën RENAULT, France
Guy Vallancien
Université René Descartes, France

ESV 2009

Table 1 : PMHS Main Characteristics

PMHS #	586	588
Age	74	88
Sex	M	M
Total weight (kg)	77	69
height (m)	1.76	1.67
Thigh height (m)	0.46	0.46
Lower leg height (m)	0.55	0.52

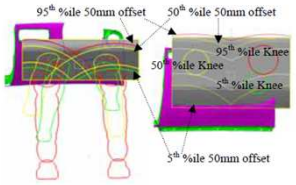
No Injury



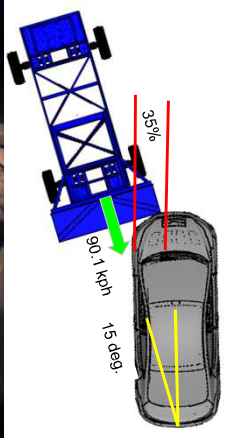
Leg Injury Hypotheses - KAB

1. KAB causes injuries in Out-of-Position scenarios.

2. KAB has insufficient coverage or energy absorption.



NHTSA Small Overlap/Oblique Test

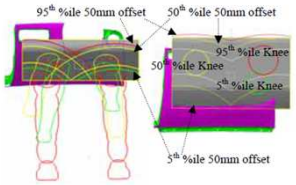


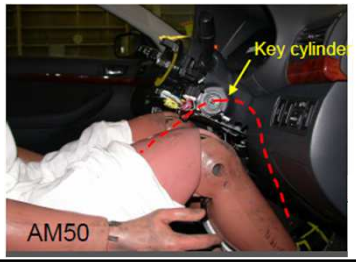
Leg Injury Hypotheses - KAB

1. KAB causes injuries in Out-of-Position scenarios.

2. KAB has insufficient coverage or energy absorption.

3. KAB somehow detrimentally affects lower extremity kinematics.





Research Approach

CIREN Case Review	Experimental Test Data Collect and Review
Computational Parametric Evaluation	Prospective Data Collection

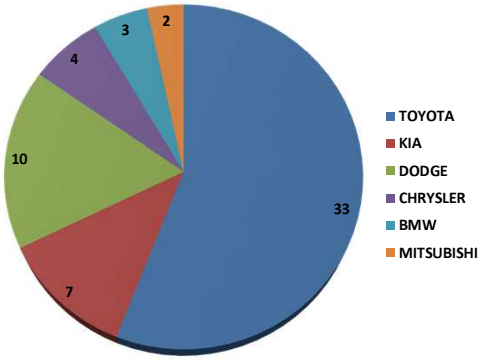
Research Approach

CIREN Case Review	**Experimental Test Data Collect and Review**
Computational Parametric Evaluation	**Prospective Data Collection**

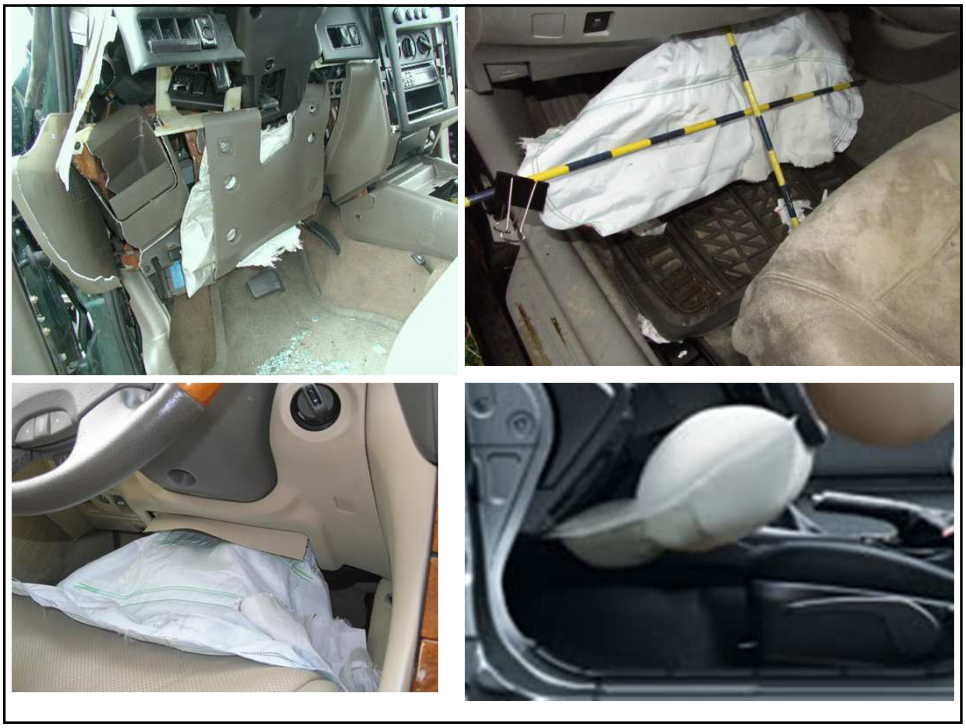
CIREN Case Summary

(59 cases with knee airbag deployed, driver side only)

Manufacturer Distribution of Cases



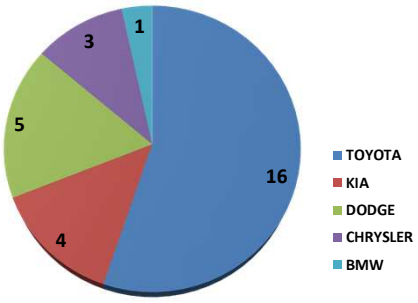
TOYOTA	TOTAL	31
	CAMRY	14
	SCION TC	13
	AVALON	2
	HIGHLANDER	1
	4-RUNNER	1
LEXUS	TOTAL	2
KIA	TOTAL	7
	SPORTAGE	6
	SORENTO	1
DODGE	TOTAL	10
	CALIBER	4
	CARAVAN	6
CHRYSLER	TOTAL	4
	TOWN AND COUNTRY	2
	PACIFICA	1
	PT CRUISER	1
BMW	TOTAL	3
	Z4	1
	6 SERIES	2
MITSUBISHI	LANCER	2



CIREN Case Summary

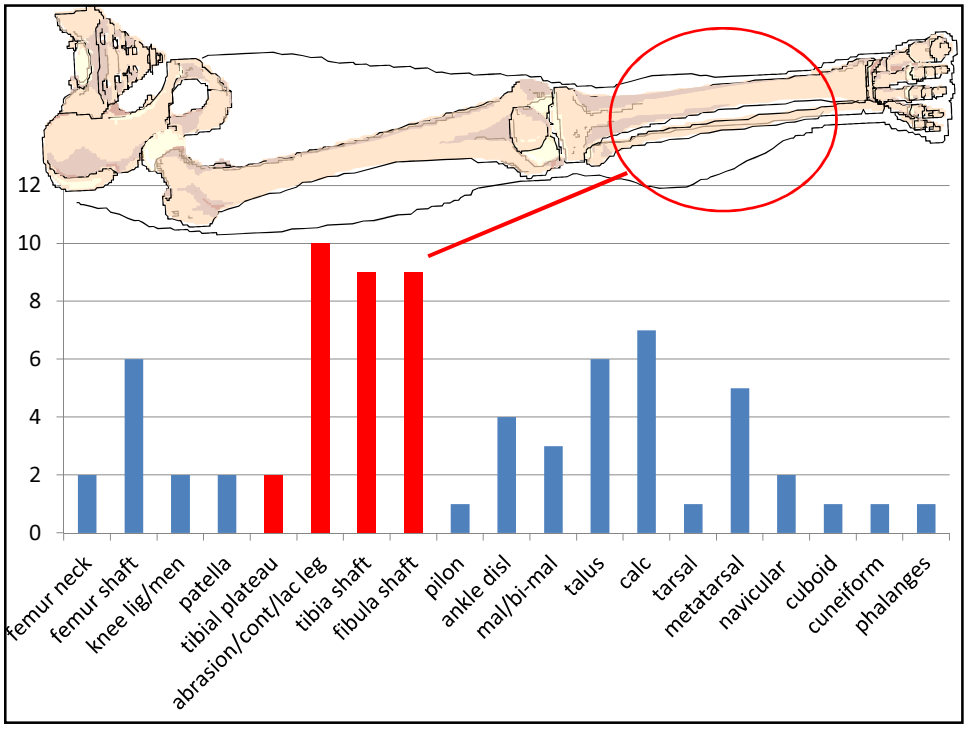
(29 cases with lower extremity injuries, knee airbag deployed, driver side only)

CIREN Case Distribution by Manufacturers



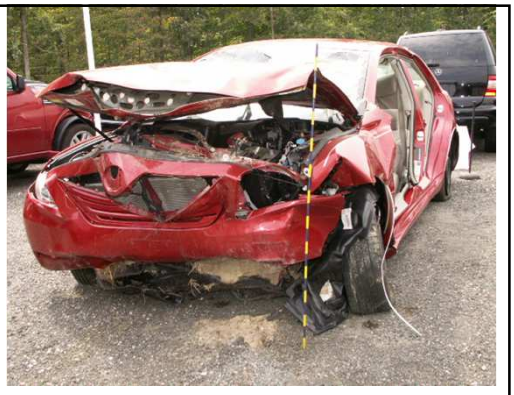
TOYOTA	TOTAL	16
	CAMRY	6
	SCION TC	6
	AVALON	2
	LEXUS	2
KIA	TOTAL	4
	SPORTAGE	4
DODGE	TOTAL	5
	CALIBER	1
	CARAVAN	4
CHRYSLER	TOTAL	3
	TOWN AND COUNTRY	2
	PT CRUISER	1
BMW	TOTAL	1
	6 SERIES	1
All	TOTAL	29

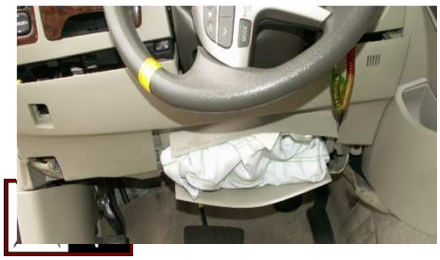
Selection Criteria: CIREN Database, 29 cases, knee airbag present and deployed, 1+ Lower extremity injuries, including fractures and skin contusions/abrasions



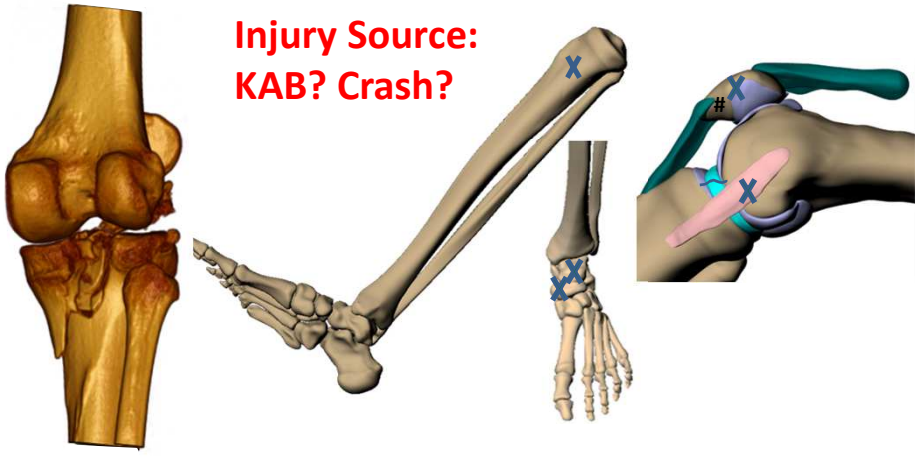
2008 Toyota Camry

- PDOF (degree)
  - 350 degrees
- CDC
  - 12FDEW03
- Delta V
  - Winsmash= 42KPH (Longitudinal 41, lateral 7)
- Topean Intrusion
  - 3 cm long, 7 cm vertical

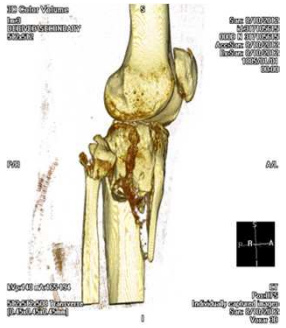




Occupant Information	Age [years]	Gender	Height [cm]	Weight [kg]
	41	F	160	68
Injury Information	MAIS	ISS	Restraints	
	5	30	• Unbelted/DAB/KAB	



Injury Source: KAB? Crash?



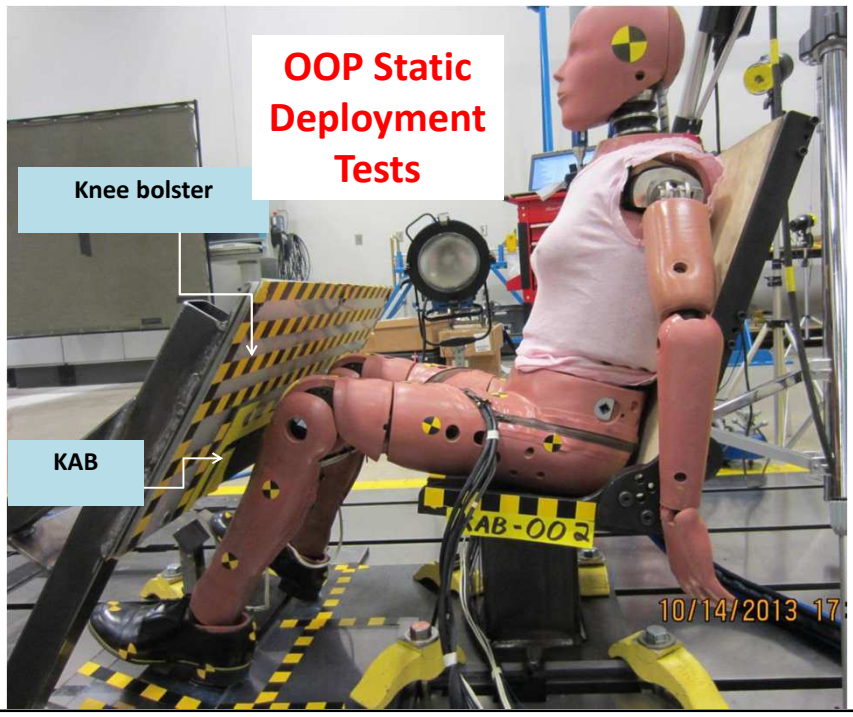
Crash year	2010
Case vehicle	2010 Toyota Camry
Crash configuration	Frontal under ride
Delta-V (km/h)	Win-smash est. 45
PDOF (degrees)	0
Age(y)/ Sex (M/F)	45/F
Stature (cm)/ Mass (kg)	173/70

Injury Source: KAB? Crash?

AIS Code	Injury Description	Aspect	Injury Mechanism
8541723	Tibia fx, proximal, complete articular, plateau; bicondylar,Schatzker 4,5,6,open	R	Axial compression+ Valgus bending
8544712	Fibula(malleoli)fx, above joint(suprasyndesmotic);isolated shaft, neck	R	External rotation

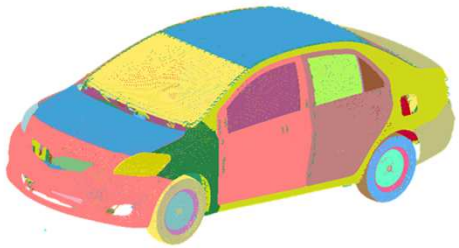
Research Approach

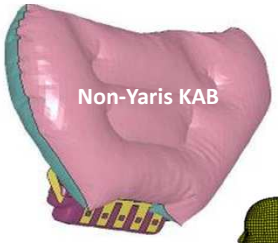
CIREN Case Review	Experimental Test Data Collect and Review
Computational Parametric Evaluation	Prospective Data Collection



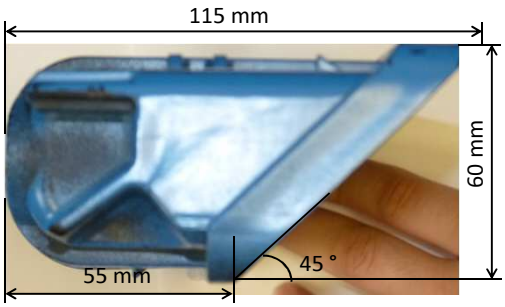
Vehicle Choice: 2010 Toyota Yaris

Not Production Knee Airbag

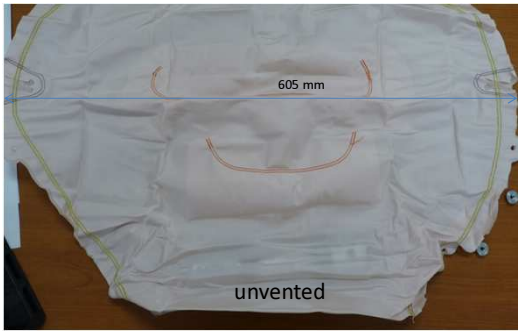


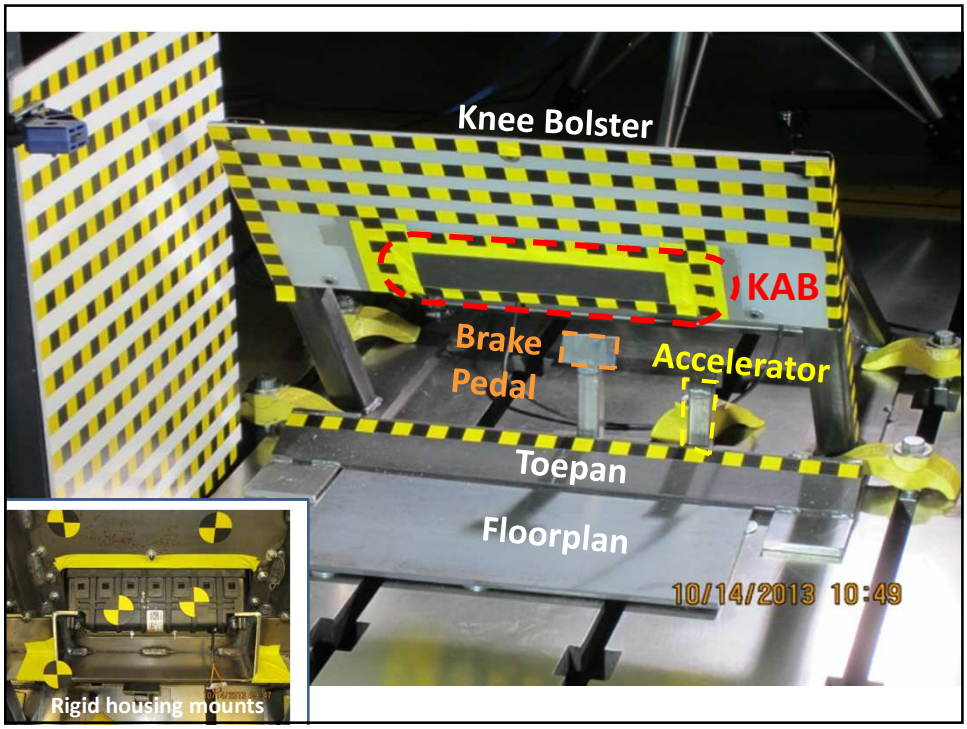


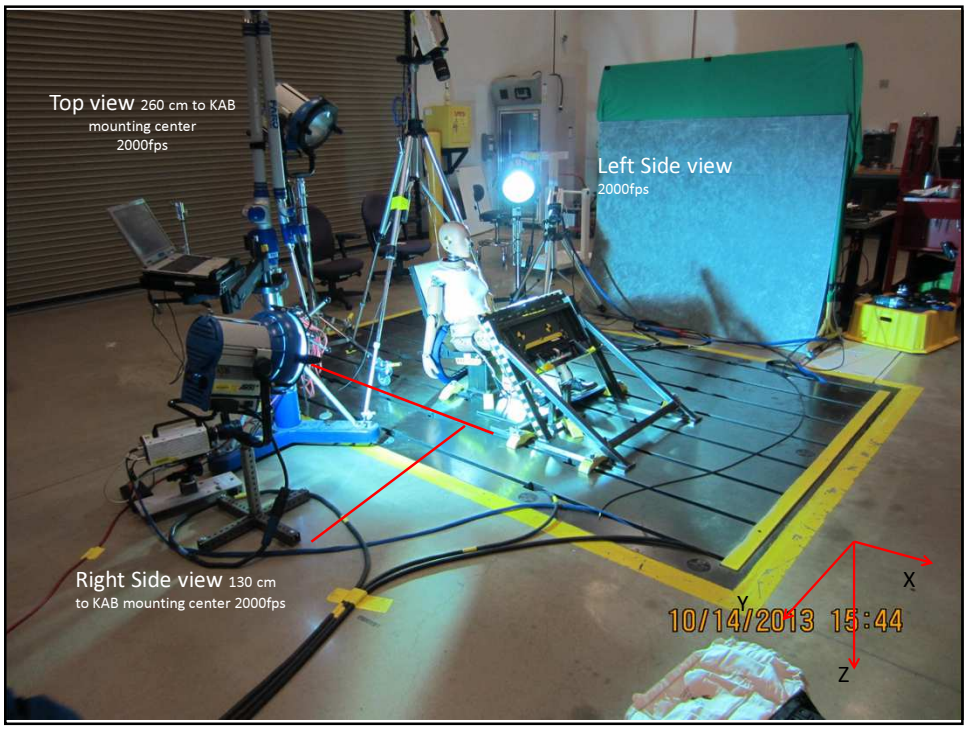
2010 Toyota Yaris FE model (NCAC)



ARC hybrid gas inflator, 194kPa max tank pressure (24.6 ms), 28.3L tank volume and 0.9 mole




Knee Bolster
KAB
Brake Pedal
Accelerator
Toepan
Floorplan
10/14/2013 10:49
Rigid housing mounts


Top view 260 cm to KAB mounting center 2000fps
Left Side view 2000fps
Right Side view 130 cm to KAB mounting center 2000fps
10/14/2013 15:44
X
Y
Z

AF5 H3 Surrogate

(tolerance, proximity)

Hybrid III 5th Leg

THOR-FLx

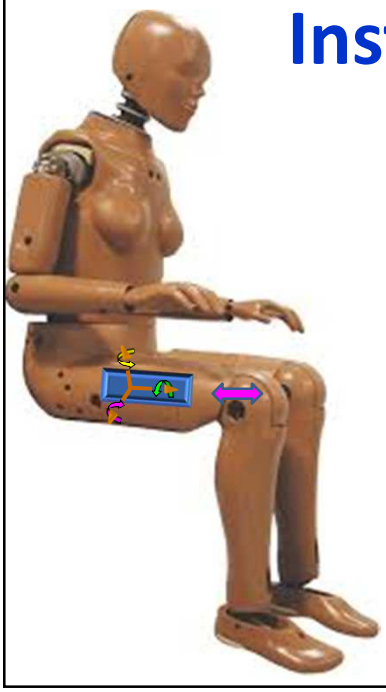
AF5 H3 Surrogate

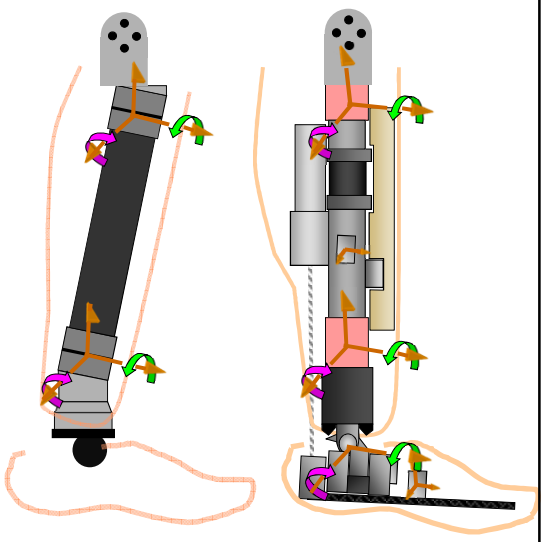
(tolerance, proximity)

Hybrid III 5th Leg

THOR-FLx

Instrumentation





Hybrid III THOR-FLx

Tibia Index/Revised Tibia Index

$$M_r = \sqrt{M_x^2 + M_y^2}$$

$$TI_{Hybrid-III} = \frac{F_z}{F_c} + \frac{M_r}{M_c} = \frac{F_z}{(-22900)} + \frac{M_r}{115}$$

$$TI_{THOR-FLx} = \frac{F_z}{F_c} + \frac{M_r}{M_c} = \frac{F_z}{(-8600)} + \frac{M_r}{146}$$

$$My_{upper.adj} = My_{upper.meas} - (Fz_{upper})(0.01589)$$

$$My_{lower.adj} = My_{lower.meas} + (Fz_{lower})(0.004665)$$

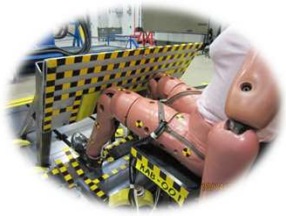
Hybrid III 5th Leg

Mertz 1993, Zuby 2001, IIHS 2014

THOR-FLx

Kuppa 2001

Design of Experiments: KAB OOP Tests

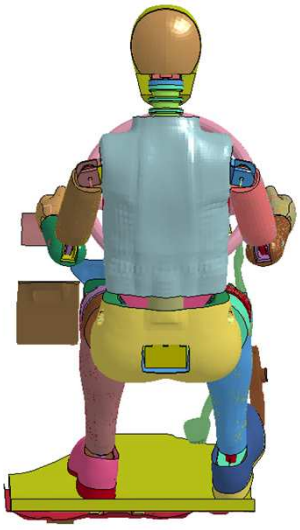


Knee to IP distance

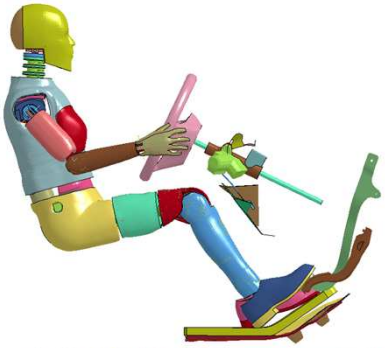
Knee-to-Knee distance

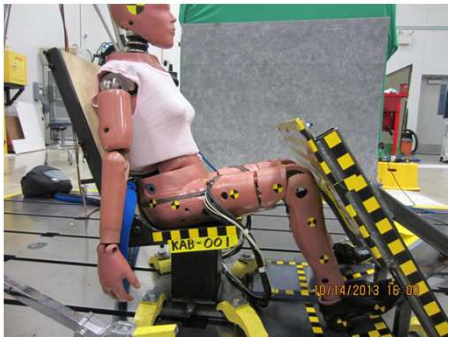
Foot placement

Baseline Position (NCAP Position)

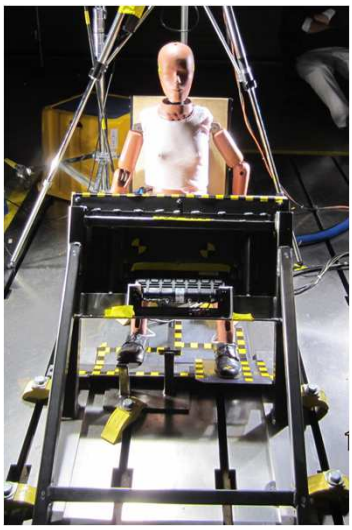


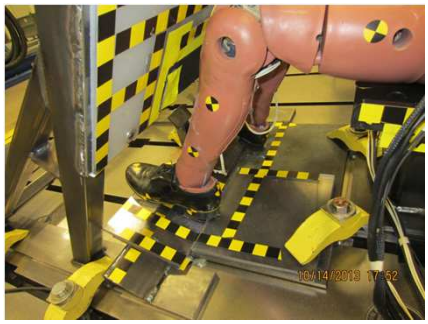
Knee-to-Knee: 252 mm

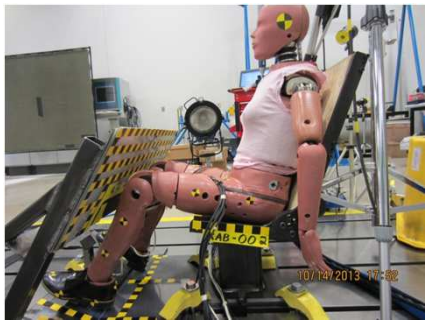




Baseline Position (NCAP Position)

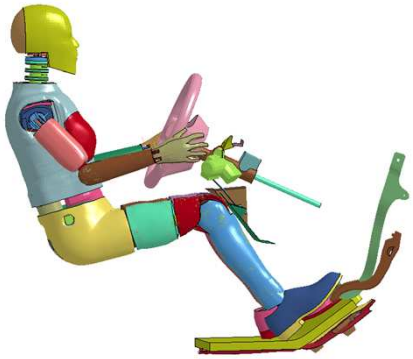


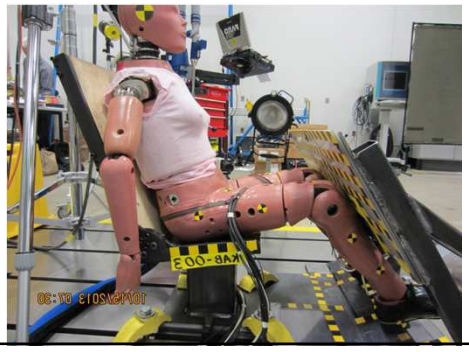




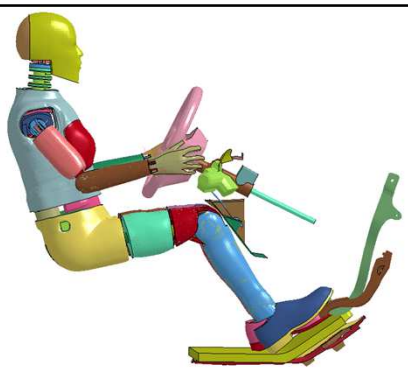
Full Forward

Knee-to-Knee: 252 mm



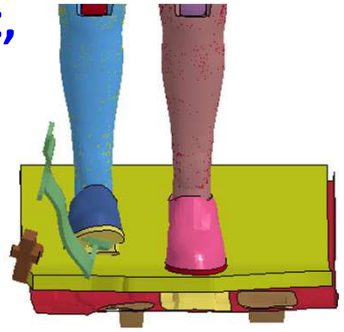


Forward, Right Foot Brake

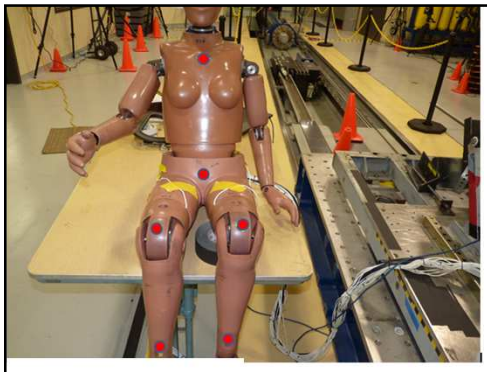


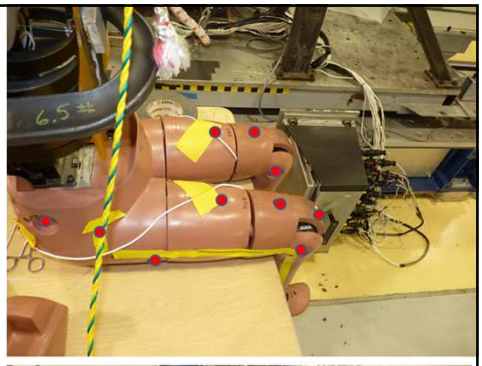
Knee-to-Knee: 180 mm

Forward, Adducted Left, Right Foot Brake Pedal



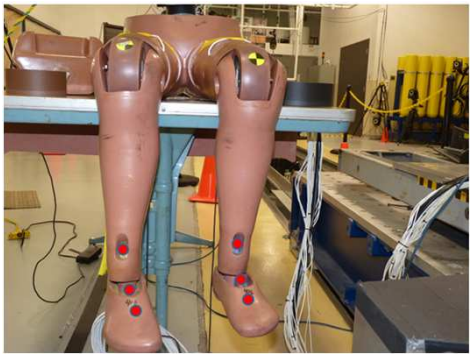
Knee-to-Knee: 150 mm

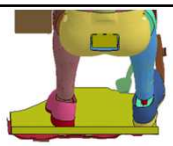




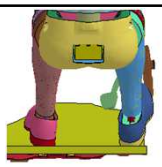
FARO Arm
< 5 mm Repeatability

Digital Inclinometer
< 5° Repeatability





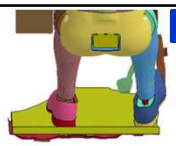
Baseline vs. Forward

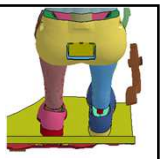


Baseline position

Knees forward

Baseline vs. FWD, R. Brake L. Adducted



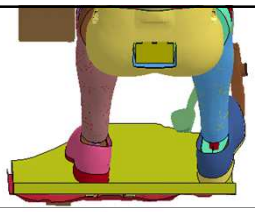


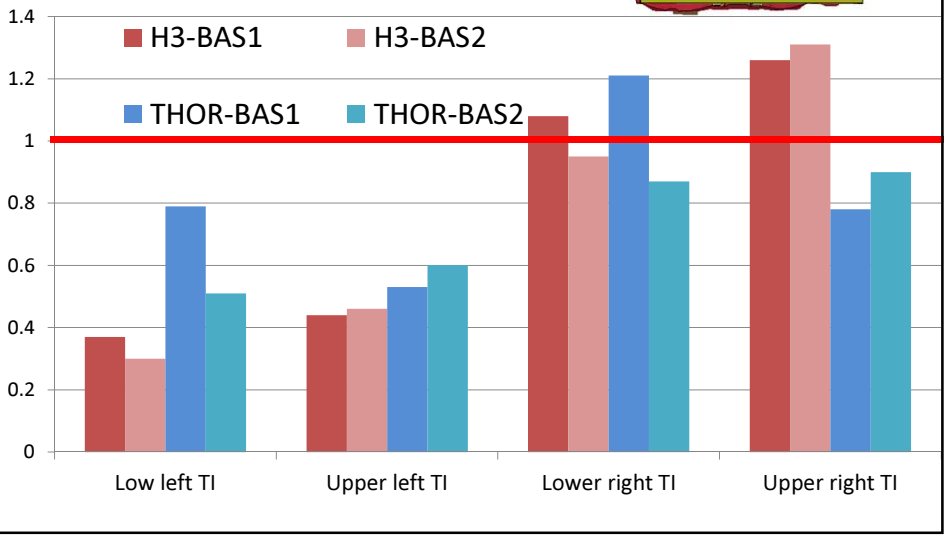
Baseline

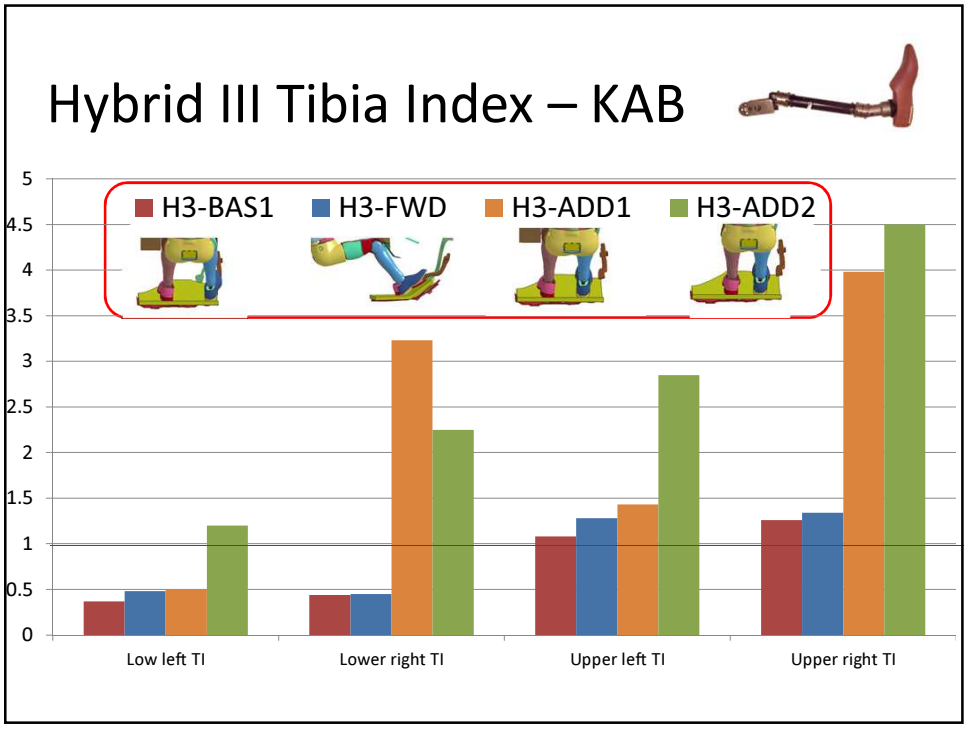
FWD, R. Brake, L ADD

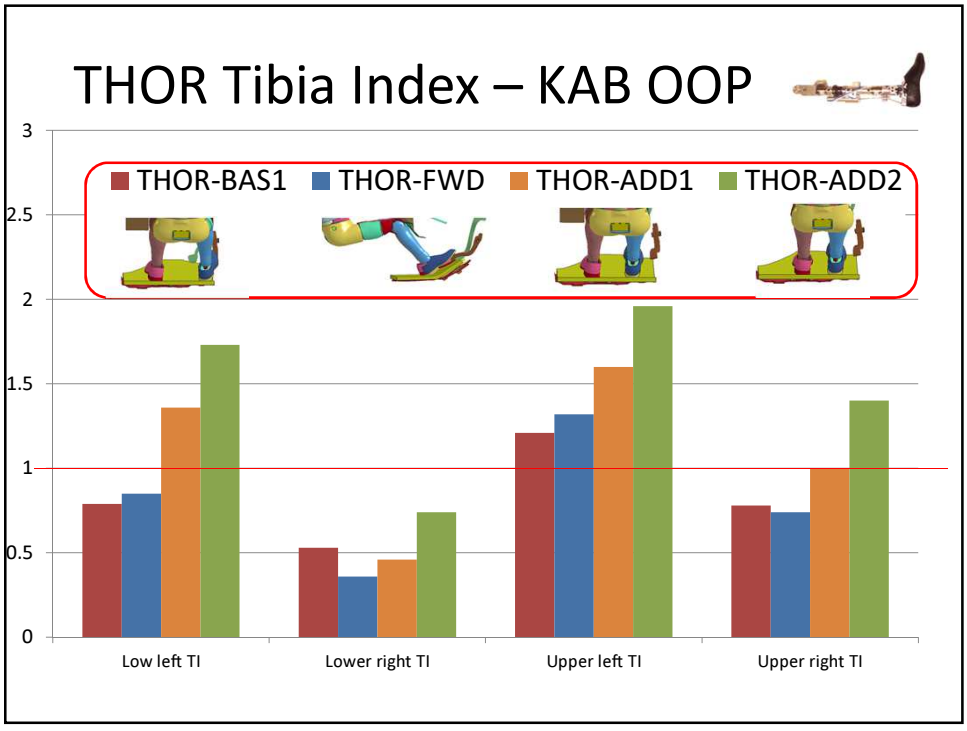
Tibia Index: Baseline

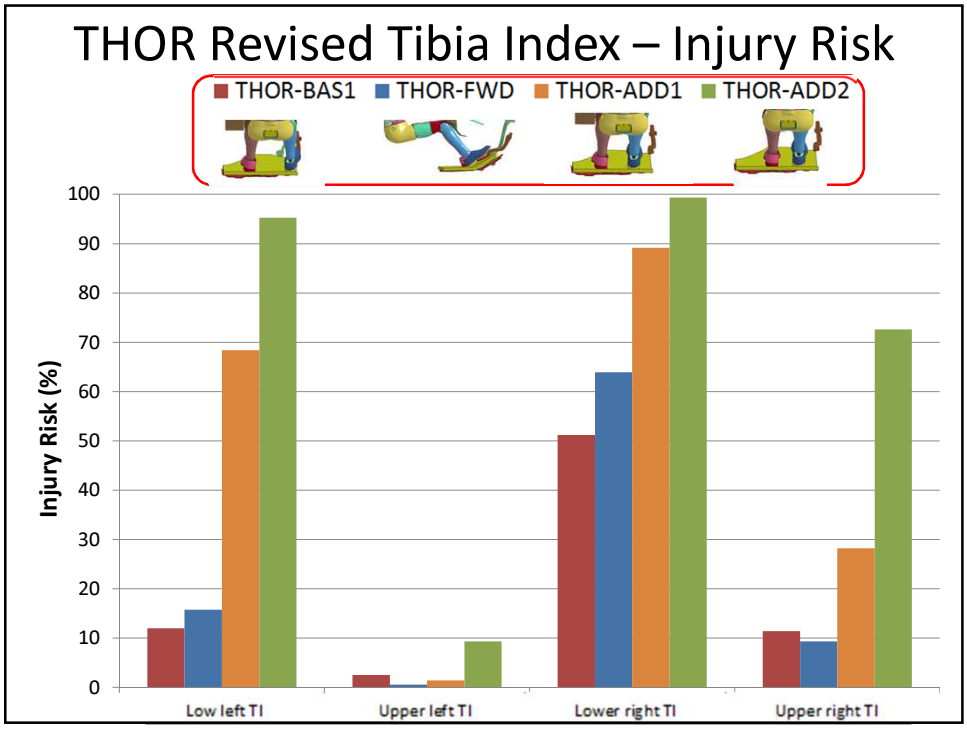
$$\frac{F_z}{F_c} + \frac{M_r}{M_c}$$






Hybrid III Tibia Index – KAB
H3-BAS1
H3-FWD
H3-ADD1
H3-ADD2
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Low left TI
Lower right TI
Upper left TI
Upper right TI


THOR Tibia Index – KAB OOP
THOR-BAS1
THOR-FWD
THOR-ADD1
THOR-ADD2
3
2.5
2
1.5
1
0.5
0
Low left TI
Lower right TI
Upper left TI
Upper right TI

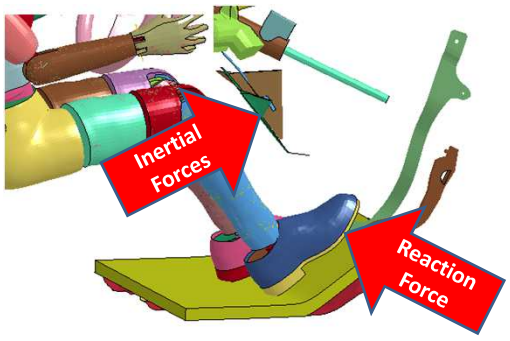


Research Approach

CIREN Case Review	Experimental Test Data Collect and Review
Computational Parametric Evaluation	Prospective Data Collection

Additional Factors to Consider

- Dynamic Tests
- Reaction force with brake pedal
- Inflator characteristics
- Bag geometry, folding, and deployment path



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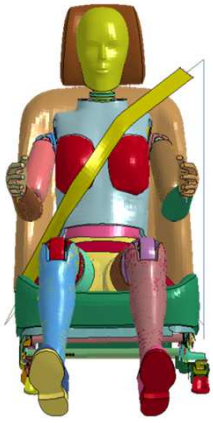
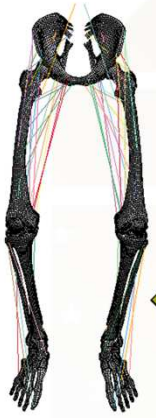
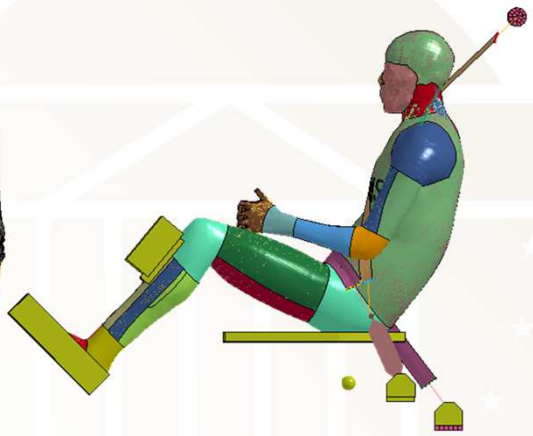
Hybrid III 5th Female



Lower Limb Musculature



THUMS v4 50th Male



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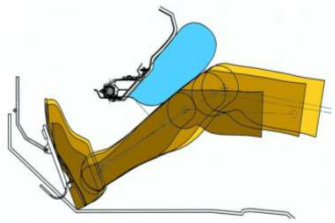
Summary



- KAB cases with lower limb injury indeterminate source of injury (crash forces, KAB, KAB altered performance/kinematics) but suggests "OOP" potential
- OOP KAB tests with 5th female H3 suggest potential for leg injury
  - Limitations/Comments: rigid supports, rigid seat, "Not Production" airbag, rear deployment
- Computational Analysis required to replicate real world include reaction forces (braking/bracing) and inertial forces (deceleration)
- 50% Vehicles with KAB by 2018, continued prospective evaluation by CIREN teams

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Acknowledgment

- CIREN (NHTSA)

Driver Lower Extremity Response and Injury with Knee Airbag Deployment

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C Michetti, R. Freeth, C. Vo,
R. Rudd, M. Scarboro

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