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INOVA REGIONAL TRAUMA CENTER

Non Ankle Lower extremity Fractures in Frontal Crashes: The Importance of Occupant Height and Vehicle Type

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Non-Ankle Lower Extremity Fracture (NALEF)

Lower Extremity Regions under study:

1- Pelvis/Hip

2- Femur

3- Knee/Patella

4- Tibia/Fibula

Research Questions??

- Does the driver's height play a role in NALEF injuries?

- Does the vehicle type play a role in the type of NALEF injury?

Selection Criteria

- **Age: $\geq$ 16 Years**
- **Vehicle Make Year: $\geq$ 1996**
- **Role: <u>Belted Drivers Only</u>**
- **PDOF: 11 – 1 O'clock**
- **No Ejection**
- **No Rollover**
- **No Fire**
- **AIS $\geq$ 2**
- **The Vehicle types included in the study are:**
  - **a) Passenger Cars**
  - **b) SUV/Light Trucks**

Sample Size

1- NASS Data

- 613 cases met the selection criteria in NASS data
- 473 cases in passenger cars
- 140 cases in SUV/Light Trucks

2- CIREN Data

- 233 cases met the selection criteria in CIREN data
- 175 cases in passenger cars
- 58 in SUV/Light Trucks

Binary Logistic Regression

Logistic regression is useful for situations in which we want to be able to predict the presence or absence of a characteristic or outcome based on values of a set of predictor variables. It is similar to a linear regression model but is suited to models where the dependent variable is dichotomous. Logistic regression coefficients can be used to estimate <u>odds ratios (OR)</u> for each of the independent variables in the model.

Variables Tested

- Vehicle Type

(Passenger Cars Vs. SUV/Light Trucks)

- Height

(3 categories < 65 Inch, 65 to 69 Inch & > 69 Inch)

- Reference Values

  Vehicle type: Passenger Cars

  Height: < 65 Inch

Individual Analysis of Different Components of Non Ankle Lower Extremity Fractures

Pelvic/Hip Fracture
CIREN Data Analysis

Passenger Cars

Driver's height played a significant role in Hip/Pelvic fractures

OR =2.06 < 65 Inch : 65-69 Inch

P = 0.165

OR = 1.88 < 65 Inch : > 69 Inch

P = 0.154

SUV/Light Trucks

Driver's height did not play a significant role in Hip/Pelvic fractures

OR= 0.714 65-69 : > 69 Inch

P = 0.683

Drivers > 69 inch are less likely to sustain Pelvic/Hip fractures in SUV/Light Trucks than in Passenger Cars

OR=0.385 SUV/Light Trucks : Passenger Cars *P* = 0.171

P value is considered statistically significant if < 0.05

Pelvic/Hip Fracture
NASS Data Analysis

Passenger Cars

Driver's height played a significant role in Hip/Pelvic fractures

OR=2.70 < 65 Inch : 65 to 69 Inch

P = 0.027

OR = 1.75 < 65 Inch : > 69 Inch

P = 0.126

SUV/Light Trucks

Driver's height did not play a significant role in Hip/Pelvic fractures

OR = 1.37 65 to 69 : > 69 Inch

P = 0.599

Drivers > 69 inch are less likely to sustain Pelvic/Hip fractures in SUV/Light Trucks than in Passenger Cars

OR= 0.904 SUV/Light Trucks : Passenger Cars *P* = 0.827

P value is considered statistically significant if < 0.05

Femur Fracture
CIREN Data Analysis

Passenger Cars

Driver's height played a significant role in Femur fractures

OR = 2.28 < 65 Inch : 65 to 69 Inch

P = 0.075

OR = 2.31 < 65 Inch : > 69 Inch

P = 0.037

SUV/Light Trucks

Driver's height did not play a significant role in Femur fractures

OR = 0.639 65 to 69 : > 69 Inch

P = 0.507

Drivers > 69 inch are less likely to sustain Femur fractures in SUV/Light Trucks than in Passenger Cars

OR = 0.416 SUV/Light Trucks : Passenger Cars *P* = 0.131

P value is considered statistically significant if < 0.05

Femur Fracture
NASS Data Analysis

Passenger Cars

Driver's height played a significant role in Femur fractures

OR = 2.29 < 65 Inch : 65 to 69 Inch

P = 0.075

OR = 1.65 < 65 Inch : > 69 Inch

P = 0.154

SUV/Light Trucks

Driver's height did not play a significant role in Femur fractures

OR = 0.436 < 65 to 65 to 69 Inch

P = 0.386

OR = 0.382 <65 to > 69 Inch

P = 0.191

Drivers > 69 inch are less likely to sustain Femur fractures in SUV/Light Trucks than in Passenger Cars

OR = 0.288 SUV/Light Trucks : Passenger Cars *P* = 0.054

P value is considered statistically significant if < 0.05

Knee/Patella
CIREN Data Analysis

Passenger Cars

Taller drivers were less likely to sustain Knee/Patella fractures than shorter drivers

(The results are statistically insignificant)

OR = 0.777 65 to 69 : < 65 Inch : Inch

P = 0.674

OR = 0.963 > 69 : < 65 Inch Inch

P = 0.945

SUV/Light Trucks

Taller drivers were less likely to sustain Knee/Patella fractures than shorter drivers

OR = 0.818 65 to 69 : < 65 Inch

P = 0.876

OR = 0.221 > 69 : < 65 Inch

P = 0.081

P value is considered statistically significant if < 0.05

Knee/Patella
CIREN Data Analysis

Drivers < 65 inch are more likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars

OR = 1.615 Passenger Cars : SUV/Light Trucks *P* = 0.672

Drivers 65 to 69 inch are less likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars

OR = 0.352 SUV/Light Trucks : Passenger Cars *P* = 0.063

Drivers > 69 inch are more likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars

OR = 1.535 Passenger Cars : SUV/Light Trucks *P* = 0.617

P value is considered statistically significant if < 0.05

Knee/Patella
NASS Data Analysis

Passenger Cars

Taller drivers were less likely to sustain Knee/Patella fractures than shorter drivers

(The results are statistically insignificant)

OR = 0.993 > 69 : < 65 Inch

P = 0.983

Drivers 65 to 69 inch were more likely to sustain Knee/Patella fractures than those < 65 inch

OR:- 65 to 69 : < 65 Inch : Inch 1.59

P : 0.236

SUV/Light Trucks

Taller drivers were more likely to sustain Knee/Patella fractures than shorter drivers

OR = 0.2.33 < 65 : 65 to 69 Inch

P = 0.443

OR = 2.05 > 69 : < 65 Inch

P = 0.316

P value is considered statistically significant if < 0.05

Knee/Patella
NASS Data Analysis

Drivers < 65 inch are less likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars

OR = .529 Passenger Cars : SUV/Light Trucks *P* = 0.552

Drivers 65 to 69 inch are less likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars

OR = 0.374 SUV/Light Trucks : Passenger Cars *P* = 0.119

Drivers > 69 inch are less likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars

OR = 775 Passenger Cars : SUV/Light Trucks . *P* = 0.597

P value is considered statistically significant if < 0.05

Tibia/Fibula
CIREN Data Analysis

Passenger Cars

Taller drivers were less likely to sustain Tibia/Fibula fractures than shorter drivers

OR = 0.528 65 to 69 : < 65 Inch
P = 0.148

OR = 0.607 > 69 : < 65 Inch Inch
P = 0.210

SUV/Light Trucks

Drivers 65 to 69 inch were less likely to sustain Tibia/Fibula fractures than shorter drivers

OR = 0.618 65 to 69 : < 65 Inch
P = 0.540

There was no relationship between Tibia/Fibula fracture and height > 69 inch

OR = 1.000 , *P* = 1.00

P value is considered statistically significant if < 0.05

Tibia/Fibula
CIREN Data Analysis

Drivers < 65 inch are <u>more likely</u> to sustain Tibia/Fibula fractures in Passenger Cars than SUV/Light Trucks

OR = 0.947 SUV/Light Trucks : Passenger Cars *P* = 0.939

Drivers 65 to 69 inch are <u>more likely</u> to sustain Tibia/Fibula fractures in in Passenger Cars than SUV/Light Trucks

OR = 0.673 SUV/Light Trucks : Passenger Cars *P* = 0.433

Drivers > 69 inch are <u>more likely</u> to sustain Tibia/Fibula fractures in SUV/Light Trucks than in Passenger Cars

OR = 1.109 Passenger Cars : SUV/Light Trucks *P* = 0.852

P value is considered statistically significant if < 0.05

Tibia/Fibula
NASS Data Analysis

Passenger Cars

Taller drivers were less likely to sustain Tibia/Fibula fractures than shorter drivers

OR = 0.569 65 to 69 : < 65 Inch
P = 0.099

OR = 0.456 > 69 : < 65 Inch
P = 0.013

SUV/Light Trucks

Drivers 65 to 69 inch were less likely to sustain Tibia/Fibula fractures than shorter drivers

OR = 0.571 65 to 69 : < 65 Inch
P = 0.539

Drivers > 69 inch were more likely to sustain Tibia/Fibula fracture than drivers < 65 inch

OR = 1.071 65 to 69 : < 65 Inch
P = 0.930

P value is considered statistically significant if < 0.05

Tibia/Fibula
NASS Data Analysis

Drivers < 65 inch are more likely to sustain Tibia/Fibula fractures in Passenger Cars than SUV/Light Trucks

OR = 0.435 SUV/Light Trucks : Passenger Cars *P* = 0.286

Drivers 65 to 69 inch are more likely to sustain Tibia/Fibula fractures in in Passenger Cars than in SUV/Light Trucks

OR = 0.186 SUV/Light Trucks : Passenger Cars *P* = 0.007

Drivers > 69 inch are more likely to sustain Tibia/Fibula fractures in in Passenger Cars than in SUV/Light Trucks

OR = 0.438 SUV/Light Trucks : Passenger Cars *P* = 0.157

P value is considered statistically significant if < 0.05

Attributable Source of NALEF Injuries
Belted Drivers
CIREN Data Analysis

Source of Injury	Percent
Knee bolster	40
Floor (Including Toe Pan)	24
Left instrumental panel and below	13
Left side interior surface, excluding hardware or armrest	9
Foot Control including parking brake	4
Other	9
Total	**100**

Attributable Source of NALEF Injuries

Belted Drivers In Passenger Cars
CIREN Data Analysis

NALEF		Floor (Including Toe Pan)	Foot Control including parking brake	Knee bolster	Left instrumental panel and below	Left side interior surface, excluding hardware or armrest	Other
Femur Fracture	Count	0	0	37	14	4	4
	% within NALEF	0	0	63	24	7	7
	% within Injury Source	0	0	36	41	14	15
Knee/Patella	Count	0	1	17	8	3	1
	% within NALEF	0	3	57	27	10	3
	% within Injury Source	0	8	17	24	10	4
Pelvis/Hip	Count	5	0	28	4	21	14
	% within NALEF	7	0	39	6	29	19
	% within Injury Source	7	0	27	12	72	54
Tibia/Fibula	Count	63	11	20	8	1	7
	% within NALEF	57	10	18	7	1	6
	% within Injury Source	93	92	20	24	3	27
Total	Count	68	12	102	34	29	26
	% within NALEF	25	4	38	13	11	10
	% within Injury Source	100	100	100	100	100	100

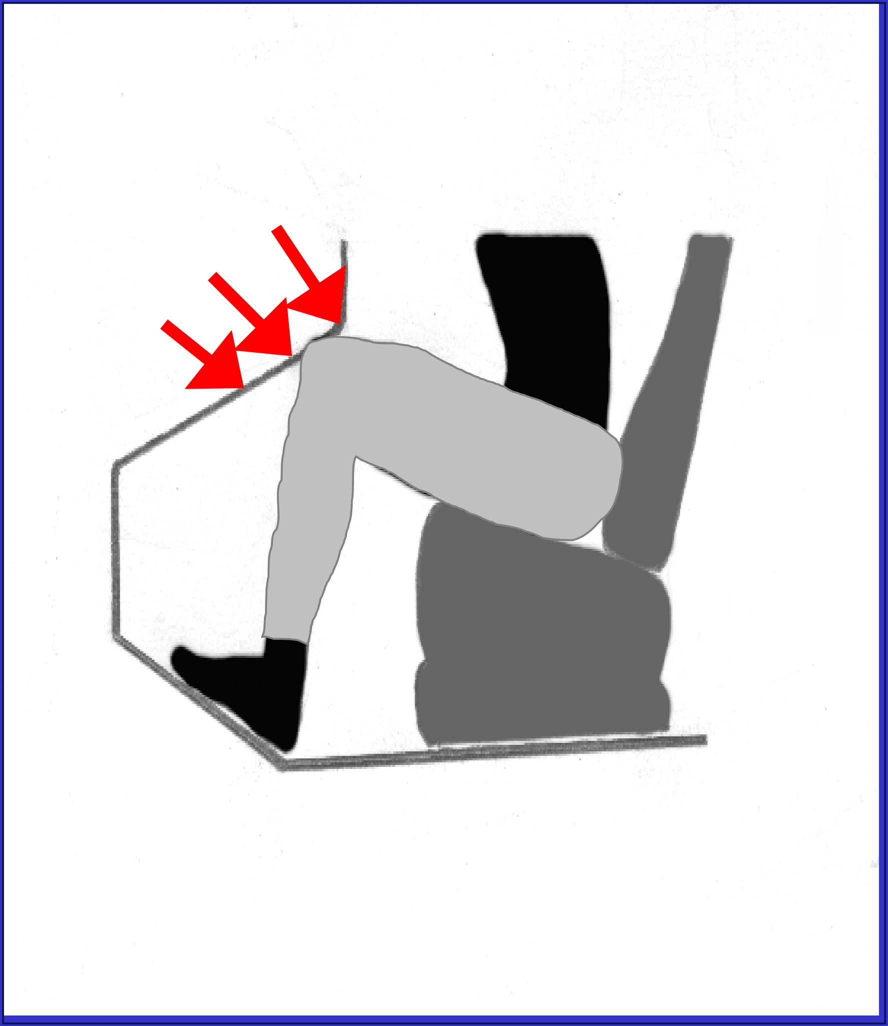
Attributable Source of NALEF Injuries

Belted Drivers In SUV/Light Trucks
CIREN Data Analysis

NALEF		Floor (Including Toe Pan)	Foot Control including parking brake	Knee bolster	Left instrumental panel and below	Left side interior surface, excluding hardware or armrest	Other
Femur Fracture	Count	0	0	16	5	1	0
	% within NALEF	0	0	72	23	5	0
	% within Injury Source	0	0	46	42	50	0
Knee/Patella	Count	0	0	7	1	0	2
	% within NALEF	0	0	70	10	0	20
	% within Injury Source	0	0	20	8	0	40
Pelvis/Hip	Count	0	0	11	2	0	0
	% within NALEF	0	0	85	15	0	0
	% within Injury Source	0	0	31	17	0	0
Tibia/Fibula	Count	16	3	1	4	1	3
	% within NALEF	57	11	4	14	4	11
	% within Injury Source	100	100	3	33	50	60
Total	Count	16	3	35	12	2	5
	% within NALEF	22	4	48	16	3	7
	% within Injury Source	100	100	100	100	100	100

Biomechanics

Role of Knee Bolster In Non-Ankle Lower Extremity Injuries



Knee Bolster

- Control Occupant Kinematics in Frontal Crash
- Distribute Lower Extremity Contact Loads
- Absorb Occupant Energy through a Body Region Capable of Accepting Restraining Forces

Culver, 1979

Lower Extremity Injury Research

- Bolster stiffness
- Knee flexion angle
- Gender
- Belt use
- Pre-impact bracing
- Intrusion

Risk of Lower Limb Injury

- Geometry
  - Occupant (Lower Extremity)
  - Vehicle (Knee Bolster, Seat)

5^{th} Female

↓

50^{th} Male

↓

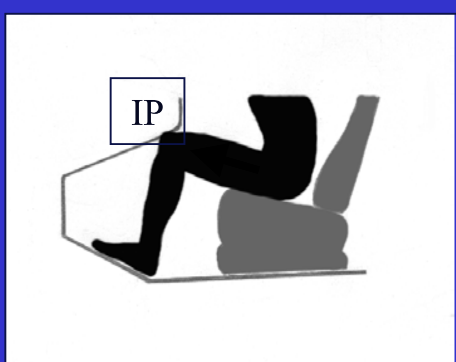
95^{th} Male

Passenger Car ⟶ SUV – Light Trucks

THIGH-KNEE LOADING

1

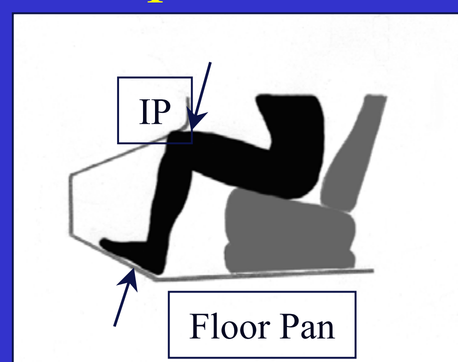
Loading axial to the thigh: potential injury to the knee-thigh-hip complex



Inertial motion causes contact with instrument panel/knee bolster

2

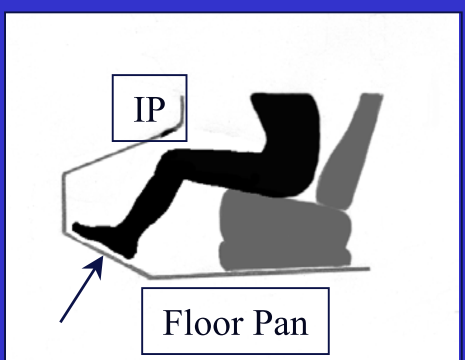
Loading axial to the leg: potential injury to the knee-leg-ankle complex



Entrapment between IP and floor pan

3

Loading axial to the entire lower extremity: potential injury to all structures

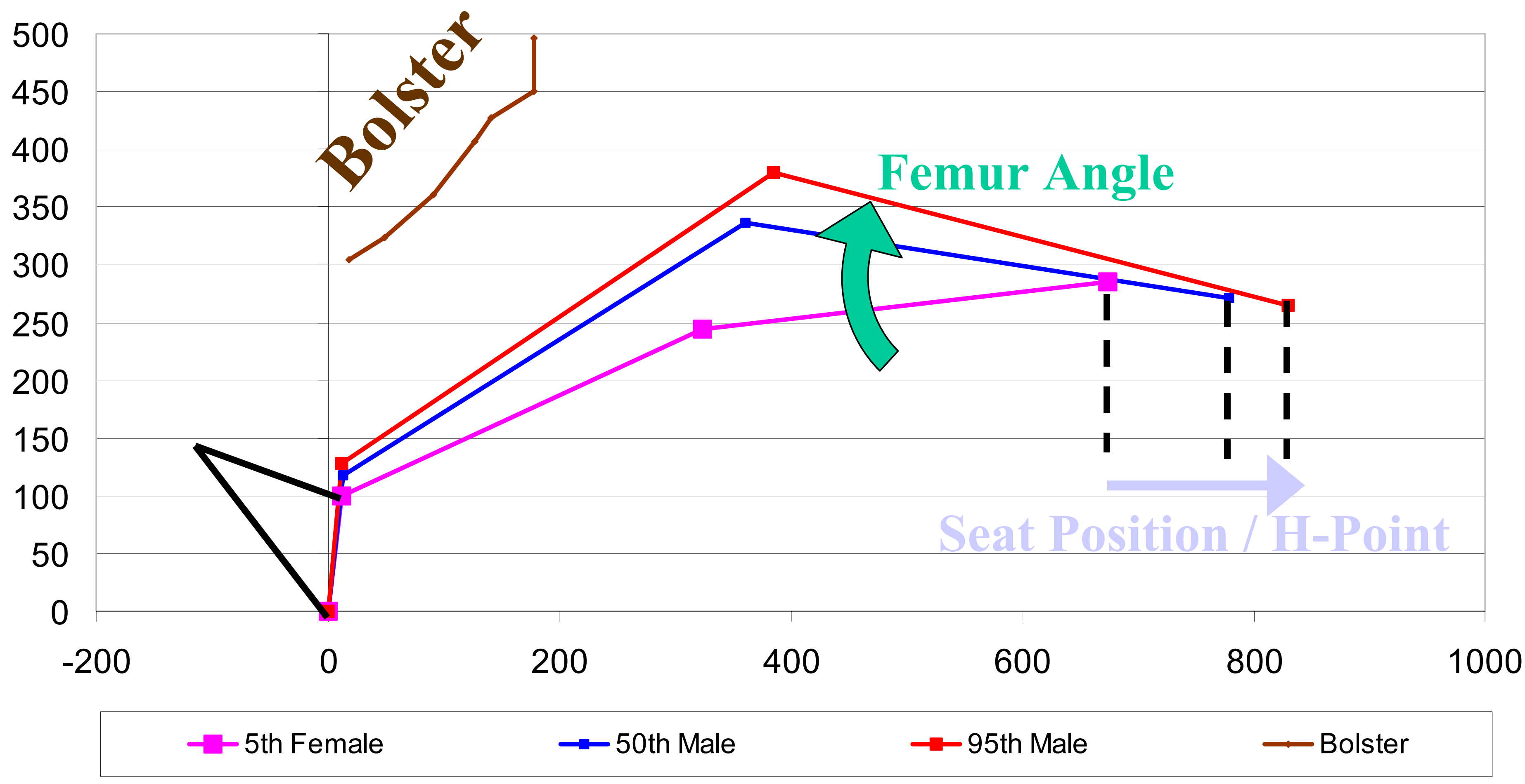


Floor pan intrusion

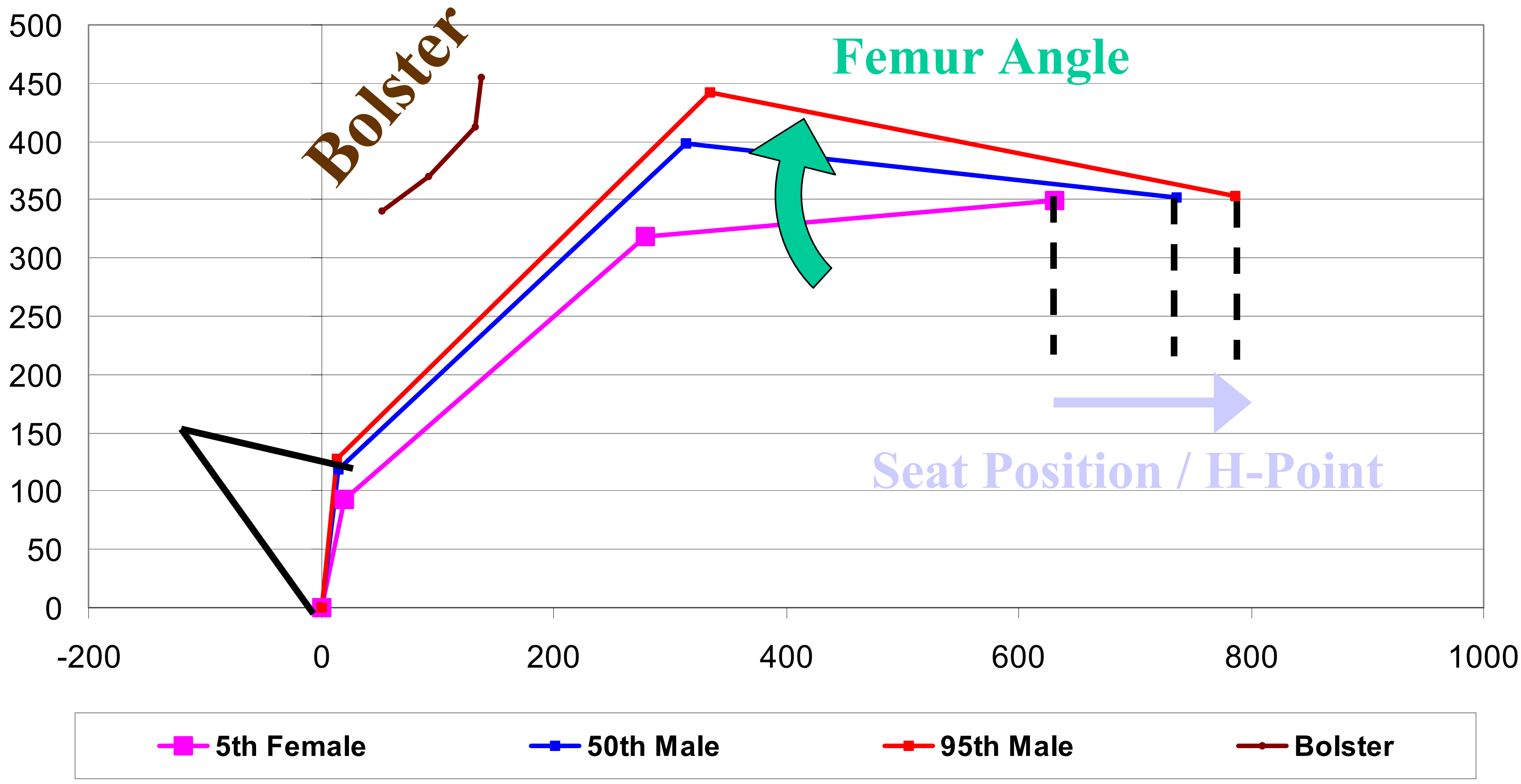
Seating Position

- University of Michigan Transportation Research Institute (UMTRI) (1996-2001)
  - Anthropometric measurements of drivers
  - Dummy Positioning Model (vehicle parameters)
  - 5^{th} Female – 4’ 11” (59”, 151 cm)
  - 50^{th} Male – 5’ 9” (69”, 175 cm)
  - 95^{th} Male – 6’ 2” (74”, 187 cm)
- Insurance Institute for Highway Safety (IIHS) Tests
  - Nissan Titan
  - Nissan Maxima

Lower Extremity Position – Nissan Maxima

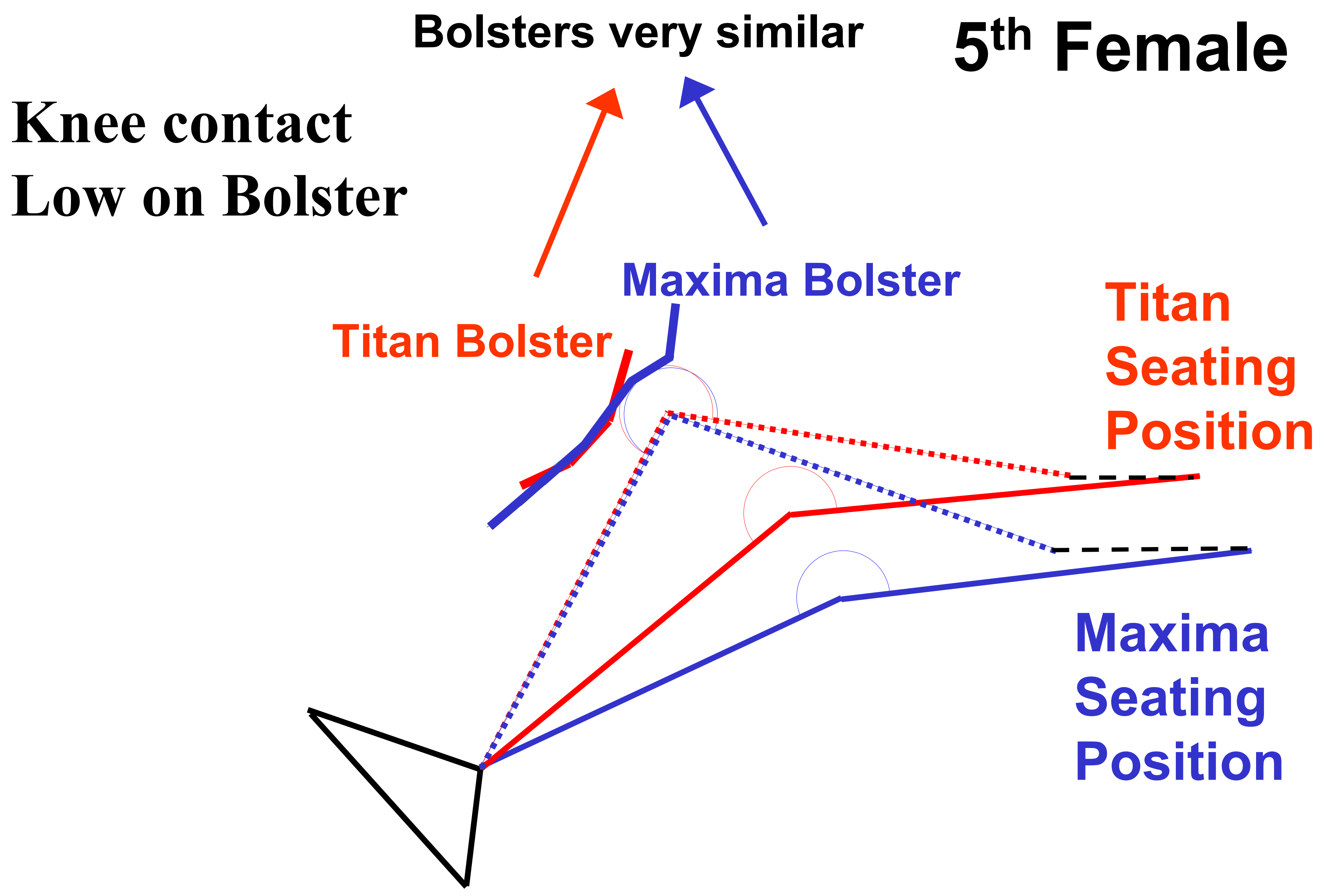


Lower Extremity Position – Nissan Titan



Estimating kinematics

- **Estimate lower extremity positions at time of contact with bolster** (Culver & Viano, 1979)
  - **Stationary ankle position**
  - **H-Point moved horizontally until contact with bolster**

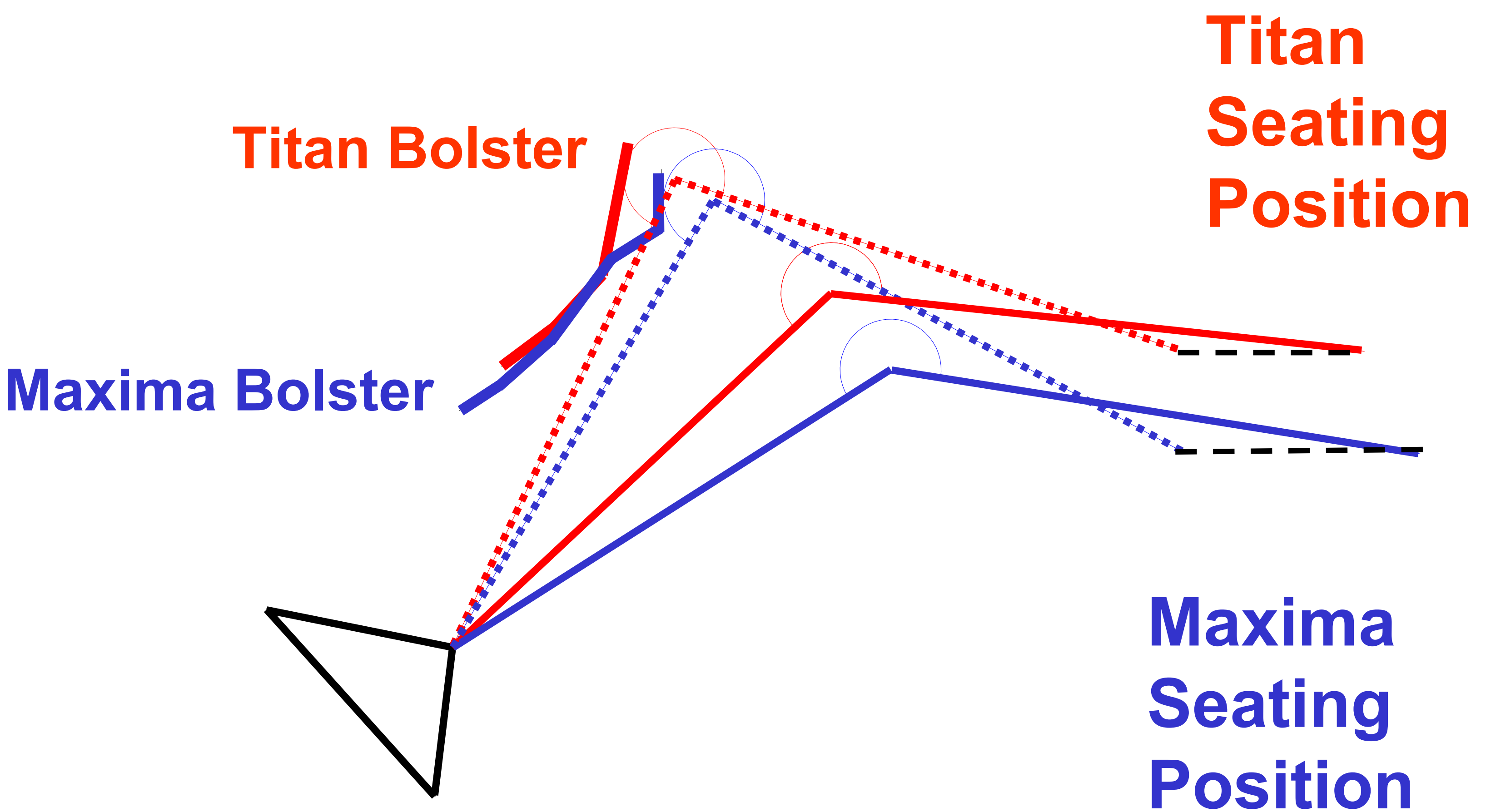


Bolsters very similar
5th Female
Knee contact
Low on Bolster
Maxima Bolster
Titan Bolster
Titan
Seating
Position
Maxima
Seating
Position

50th Male

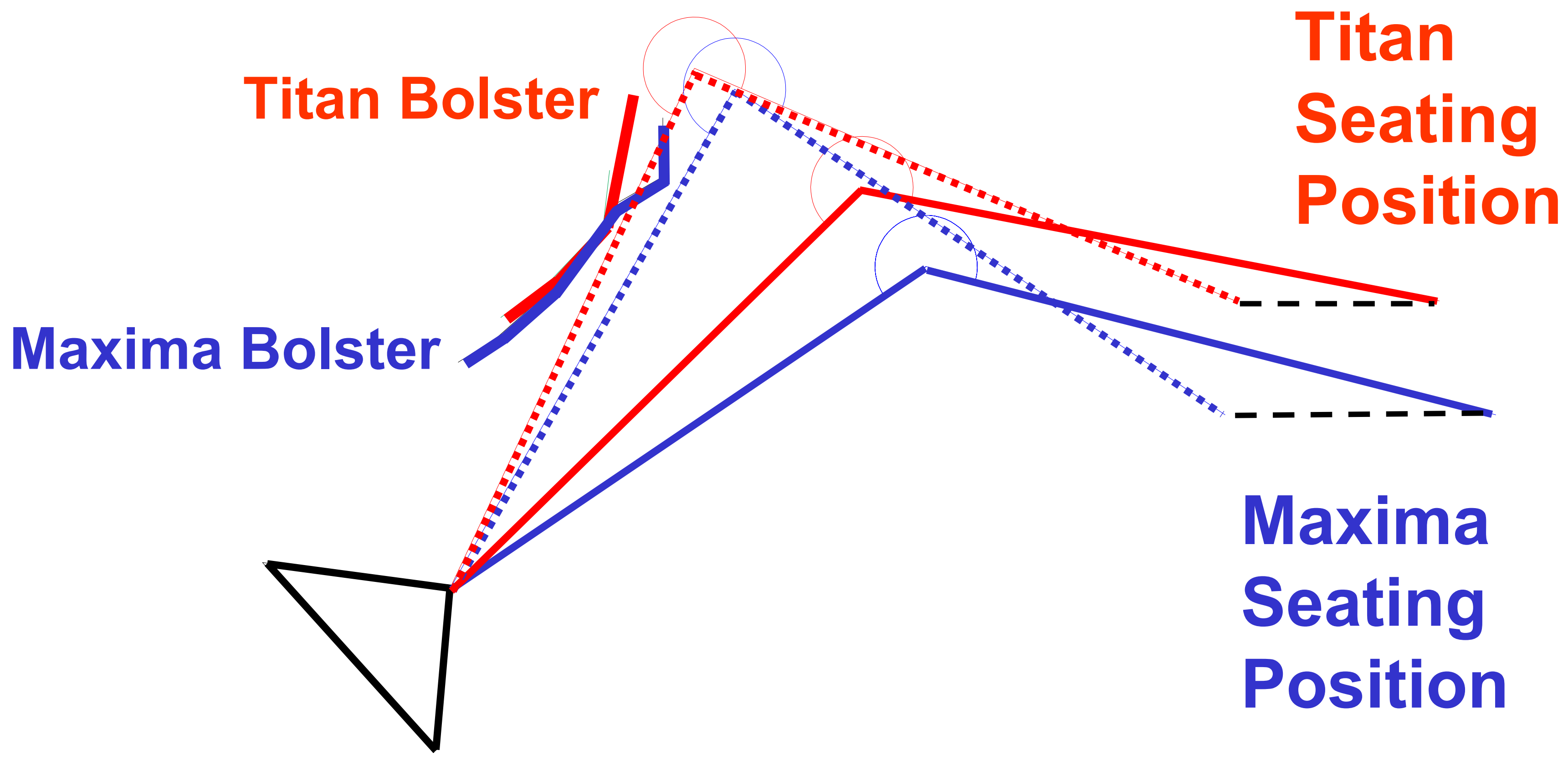
Knee contact

Knee more flexed in Pass Car

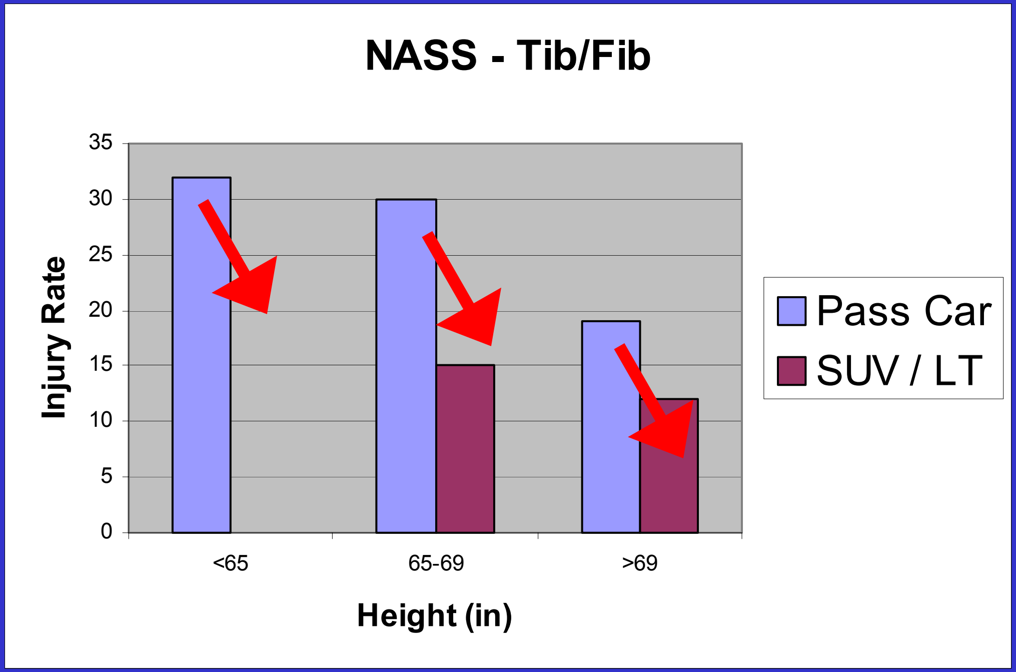


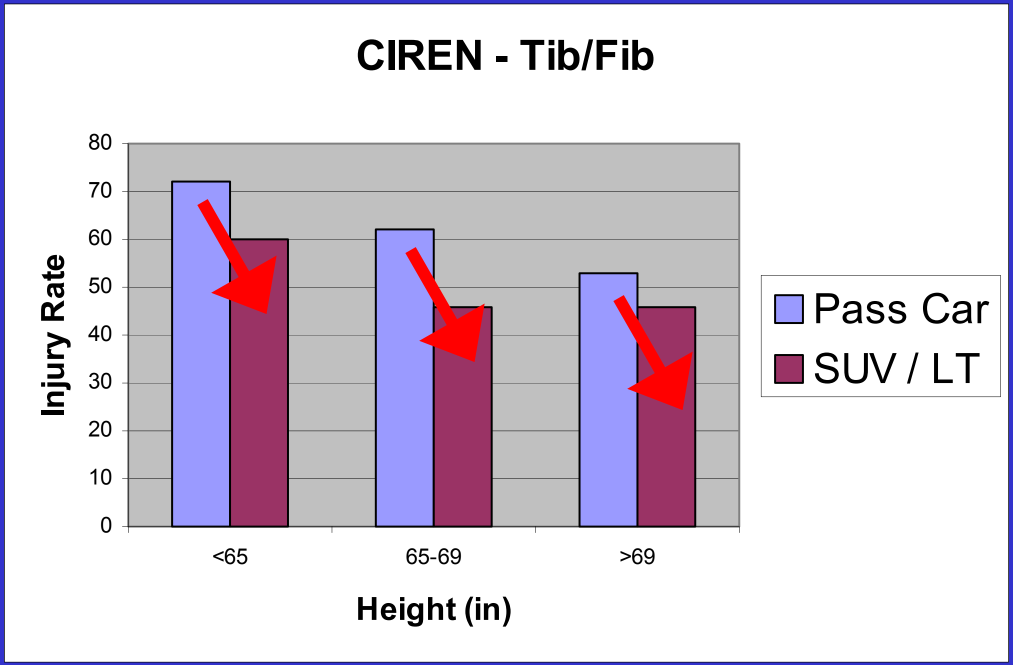
95th Male

Tibia contact
Femur more horizontal in SUV



Tibia/Fibula fractures more likely in passenger cars

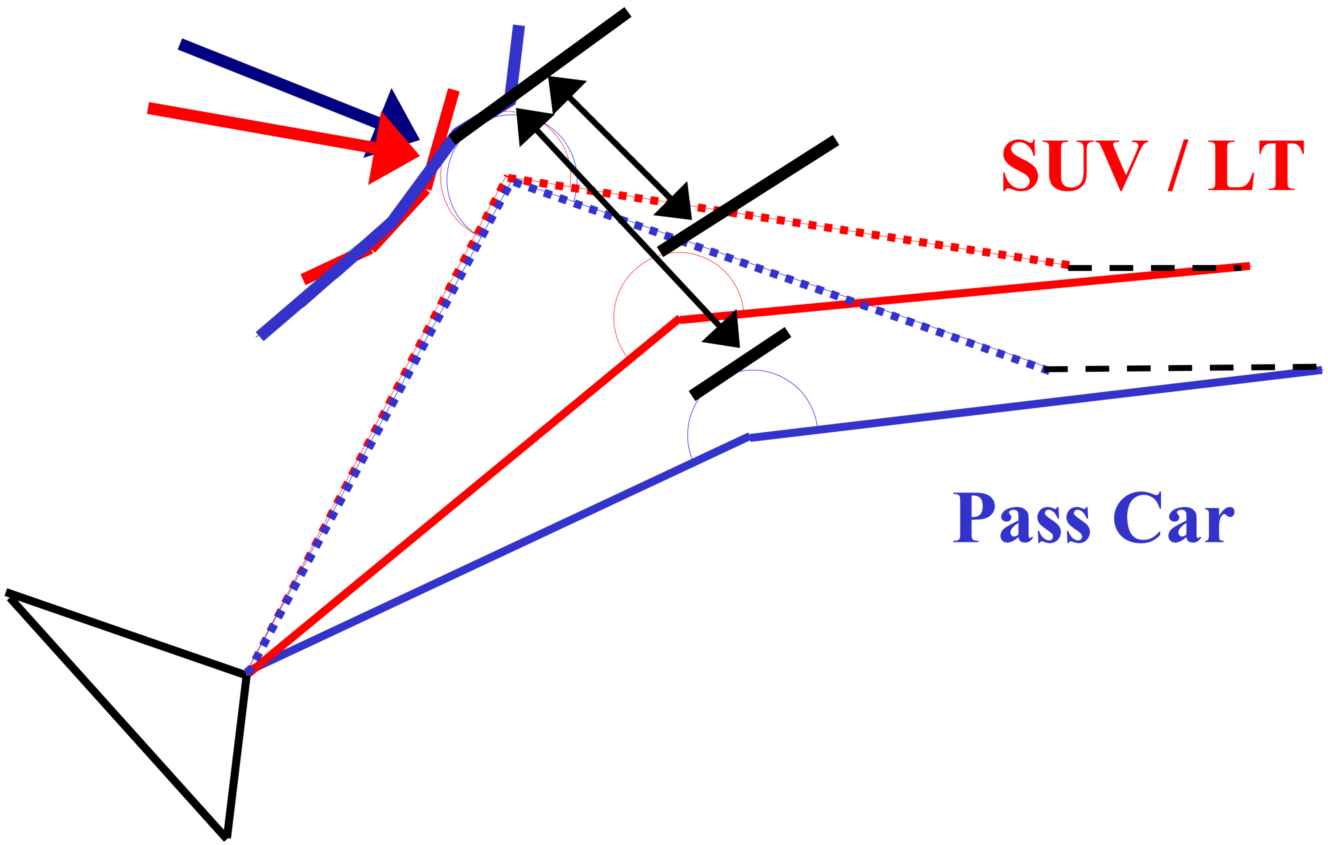


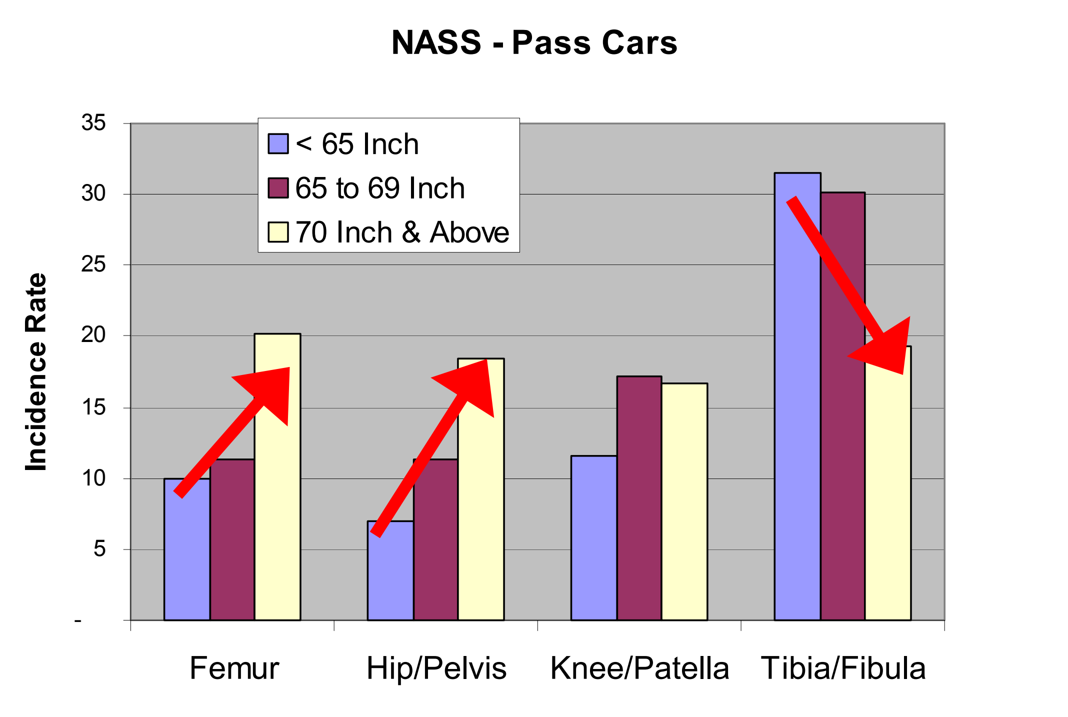


Possible reasons for increased Tib/Fib injury risk in Passenger Cars

-Knee flexion angle, bolster resistive force

-Increased distance from bolster (also increased knee/patella risk)



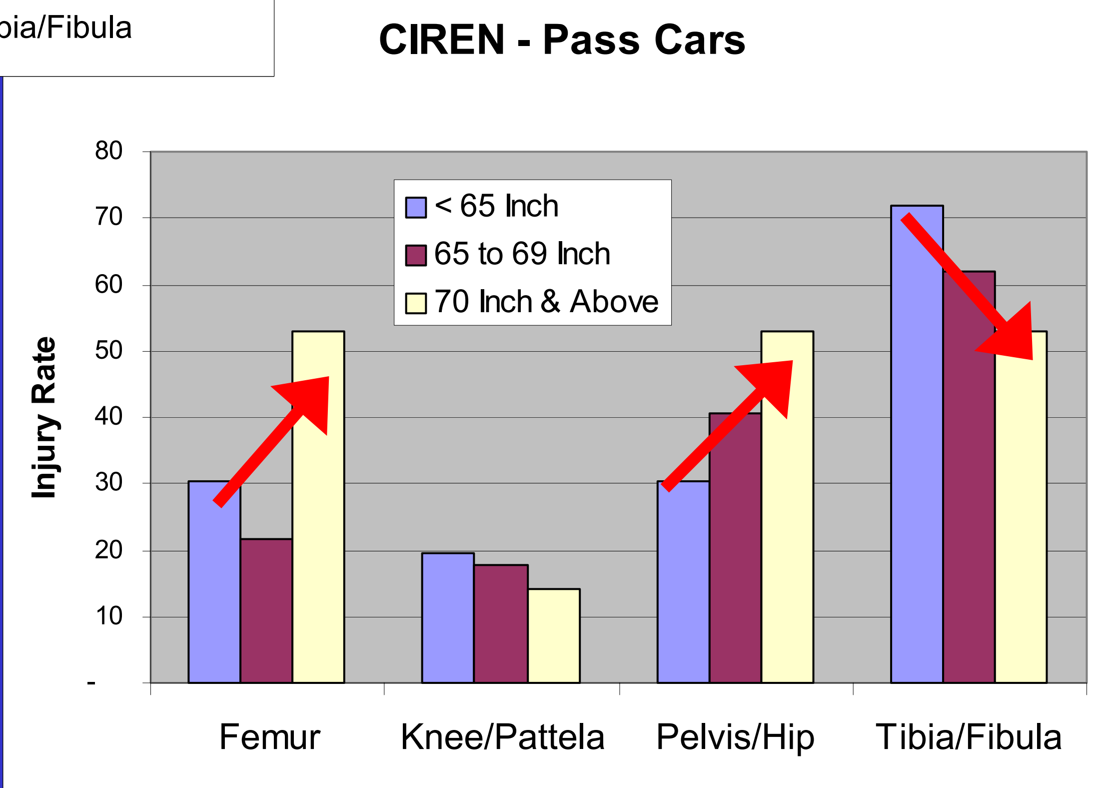


Femur and Pelvis/Hip risk increases for taller occupants

(Pass Cars)

Tibia/Fib risk decreases for taller occupants

(Pass Cars)

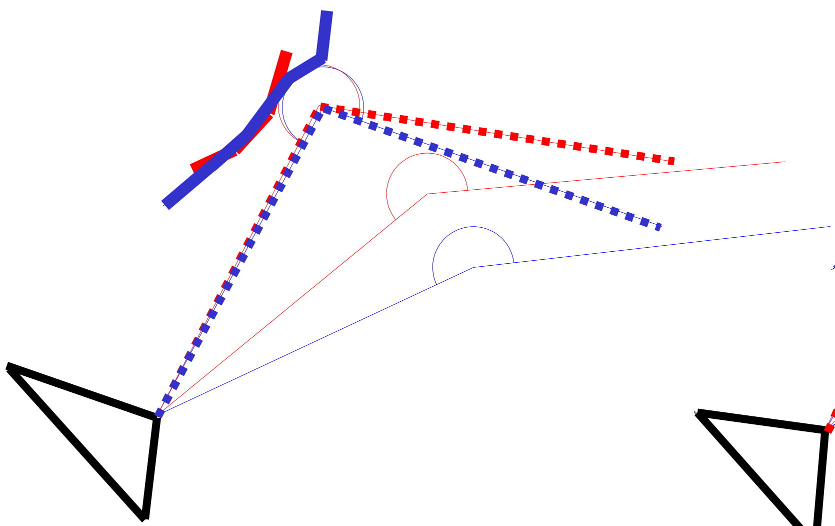


Possible reason for decreased Tib/Fib injury risk for taller occupants

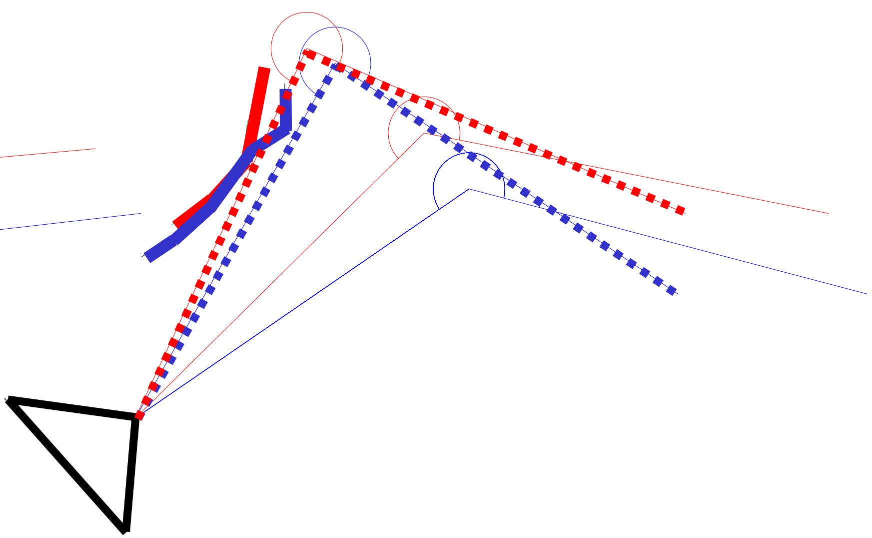
Bolster contact below knee

Tibia fractures due to compression more than bending

5th Female



95th Male



Summary

- **Preliminary analysis of lower extremity kinematics**
  - **Occupant Height**
    - **Initial distance to bolster**
    - **Anatomic location of bolster contact**
  - **Vehicle Type**
    - **Initial distance to bolster**
    - **Femur angle**
    - **Knee flexion angle**
- **May explain some differences in injury patterns**

CONCLUSIONS

- The interactions between Driver Height and Vehicle Type play a significant role in the incidence of NALEF injuries
- Eighty-two percent of NALEF injuries are attributable to the Knee Bolster and adjacent areas (Left Instrument Panel, Toe Pan, Foot Control Including Parking Brake)
- Data from CIREN are consistent with data from NASS in most of the analyses presented

RECOMMENDATIONS

- Analyses of the bio-mechanics of car crashes may be of great value in pre-hospital screening for NALEF injuries
- These observations should be considered by health care providers at the crash scene to better manage injured drivers during extrication
- Educational efforts based on these findings may be an effective tool for injury prevention
- The relationship of NALEF injuries and vehicle design require further investigation