Patterns and Factors Involved in Fractures and Dislocations to the KNEE-THIGH-HIP COMPLEX in Frontal Crashes

A preliminary analysis of the U of M CIREN Database

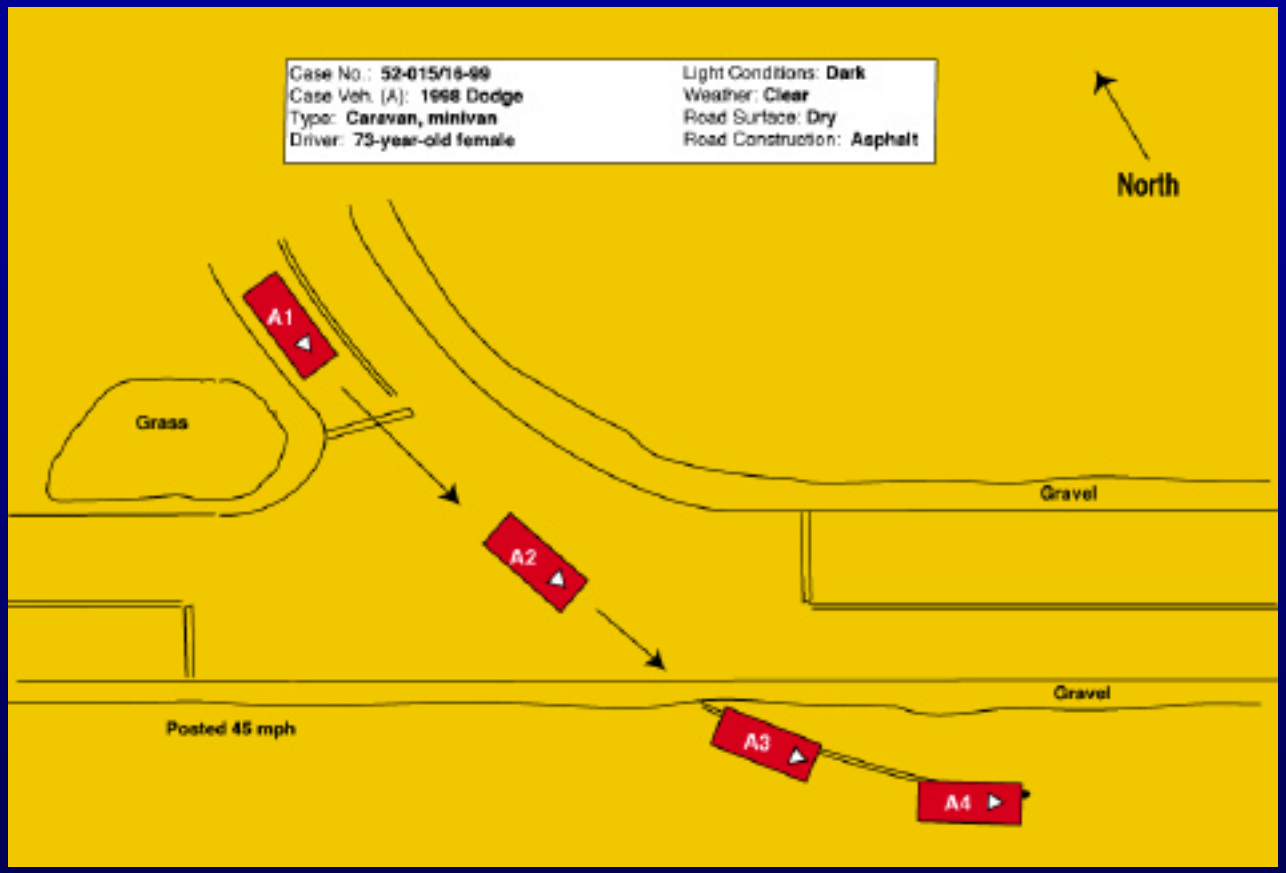
Dr. Stewart C. Wang, M.D., Ph.D.
Lawrence W. Schneider, Ph.D.
Joel B. MacWilliams

May 5, 2000
The NHTSA
Washington, D.C.

Example Case

resulting in left acetabular fracture and right femur fracture to unbelted right-front passenger in a left-sided, 24-mph offset-frontal collision with a tree

Crash Scenario



- 1998 Dodge Caravan
- Went off the road and struck a 28-cm diameter tree with the left front in an offset mode
- CDC = 12-FLEN-4
- Delta V est. at 24 mph
- 32 cm of direct damage
- 56 cm maximum crush

Crash Scene

path of case vehicle

U of M CIREN

Crash Scene

path of case vehicle

U of M CIREN

Crash Scene

path of case vehicle

U of M CIREN

Crash Scene

struck object - 28-cm diameter tree

U of M CIREN

Crash Scene

looking back on path of case vehicle

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

exterior damage

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

exterior damage

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

exterior damage

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

exterior damage

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

exterior damage

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

interior damage

Case Vehicle - 1998 Dodge Caravan

interior damage

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

interior damage - steering wheel rim

U of M CIREN

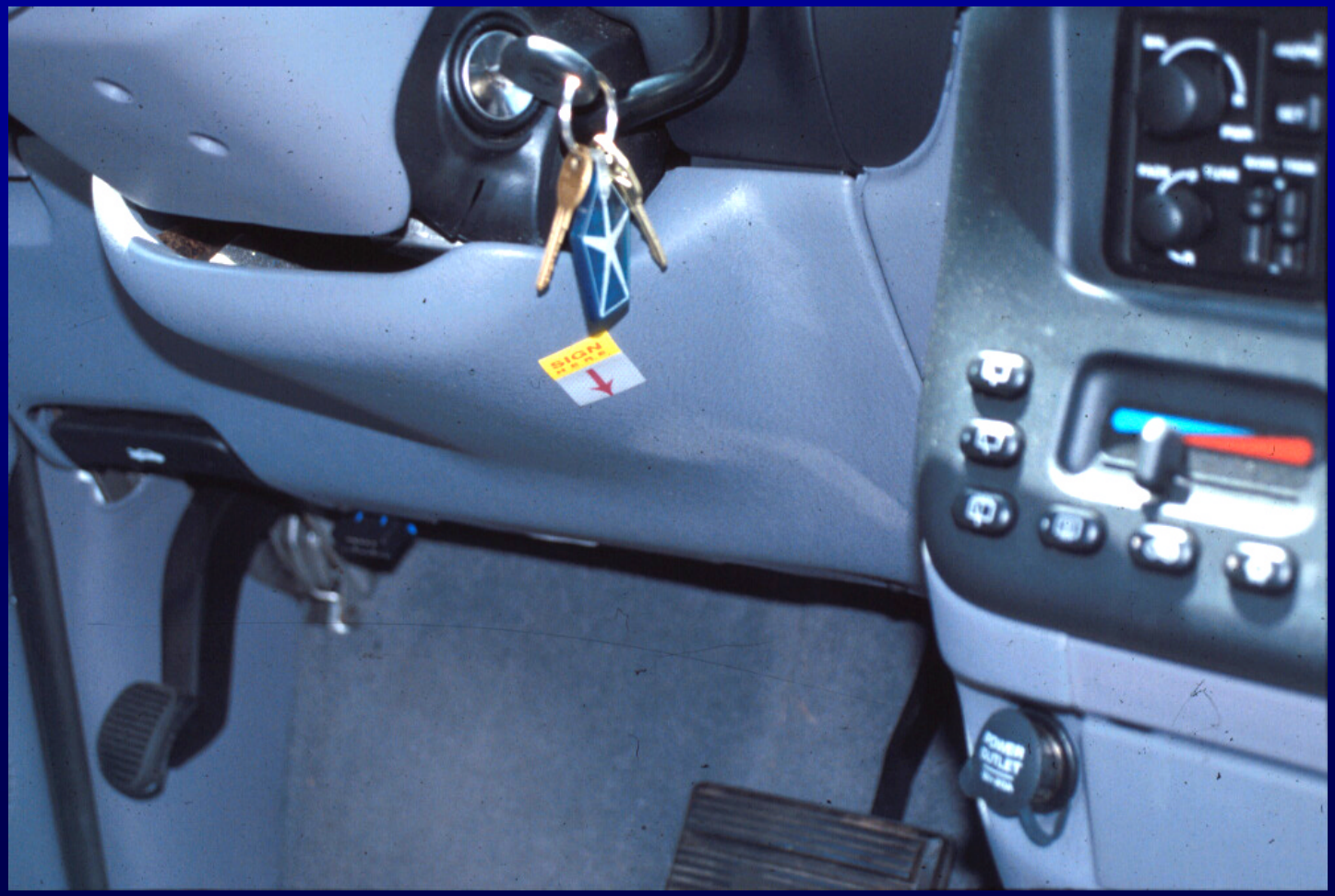
Case Vehicle - 1998 Dodge Caravan

interior damage - driver airbag and toepan area

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

interior damage - driver knee bolster area



U of M CIREN

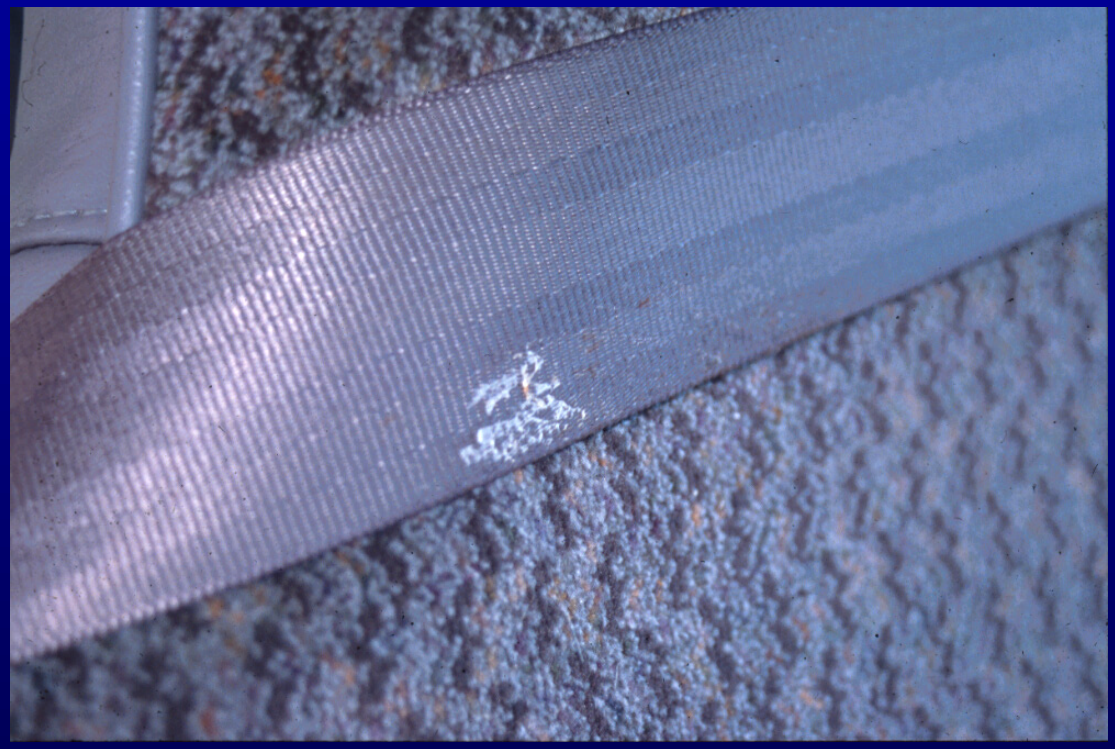
Case Vehicle - 1998 Dodge Caravan

Driver-side D-ring showing webbing imprint

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

Driver's shoulder belt



U of M CIREN

Case Vehicle - 1998 Dodge Caravan

interior toward passenger side

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

Right-front passenger D-ring showing no imprint

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

right-front passenger airbag

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

right-front passenger knee bolster area

U of M CIREN

Case Vehicle - 1998 Dodge Caravan

contact mark from RF passenger's left knee

U of M CIREN

Case Occupant
Right-Front Passenger

- 79-year-old male
- 6 ft, 0 in tall
- 175 lb
- three-point belt <u>not</u> worn
- frontal-impact airbag deployed

ER Evaluation

- Alert & oriented.
- Complained of right knee and left hip pain.
- BP 140/85, P 90, RR 20 (90% sat - 4L NC)
- Exam:
  - Chin laceration
  - Abrasions and contusions to chest and abdomen
  - Swelling of L forearm and hand
  - Bilateral knee contusion. Deformity on R.

Summary of Injuries

- AIS-4
  - Right frontal subdural hematoma, small
- AIS-3
  - Right femur supracondylar fracture
  - Left acetabular fracture (roof and posterior column)
- AIS-2
  - Metacarpal fractures
- AIS-1
  - Multiple contusions and lacerations

Treatment Course

- Post Injury Day #2:
  - Operative repair of
    - Right femur supracondylar fracture
    - Left acetabular fracture (roof and posterior column)

Treatment Course

- Post Injury Days 3 - 8
  - Renal dysfunction - oliguria
  - Cardiac dysfunction - arrhythmias, ischemia
  - Pulmonary dysfunction - ventilator dependent

Treatment Course

- **Post Injury Day #8:**
  - **Neurologic deterioration.**
  - **CT Head:**
    - **<u>R frontal subdural hematoma</u>.**

AIS-4

U of M CIREN

Treatment Course

- Post Injury Days 9-16
  - Worsening multi-organ failure.
- Post Injury Day 17
  - Care withdrawal. Patient expires.

Observations

- Elderly occupants are vulnerable to injury.
- Pre-existing conditions greatly affect outcome.
- Immobility secondary to his lower extremity injuries contributed to his poor medical outcome.

Knee/Femur/Hip Injuries Rated by Severity of Disability

- Hip fracture/dislocation involving articular cartilage
- Femoral head fracture
- Femoral neck fracture
- Supracondylar fracture
- Subtrochanteric fracture
- Shaft fracture

Hip

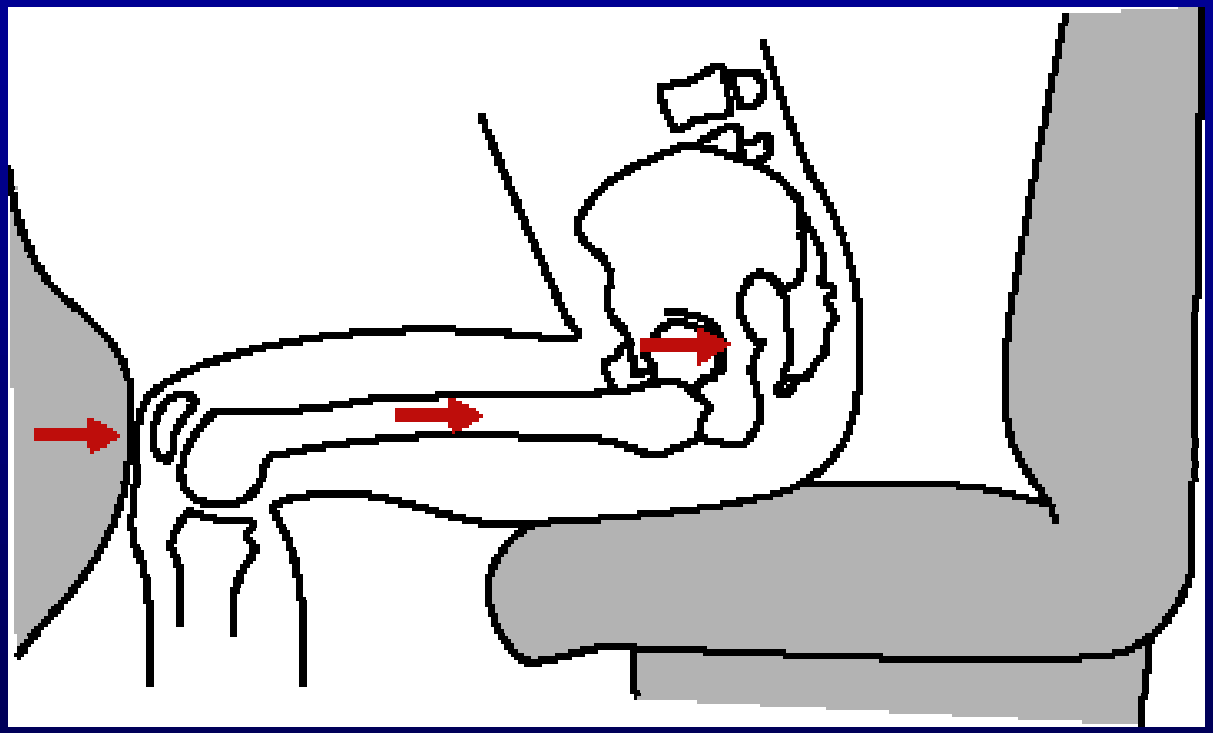
Knee

Thigh

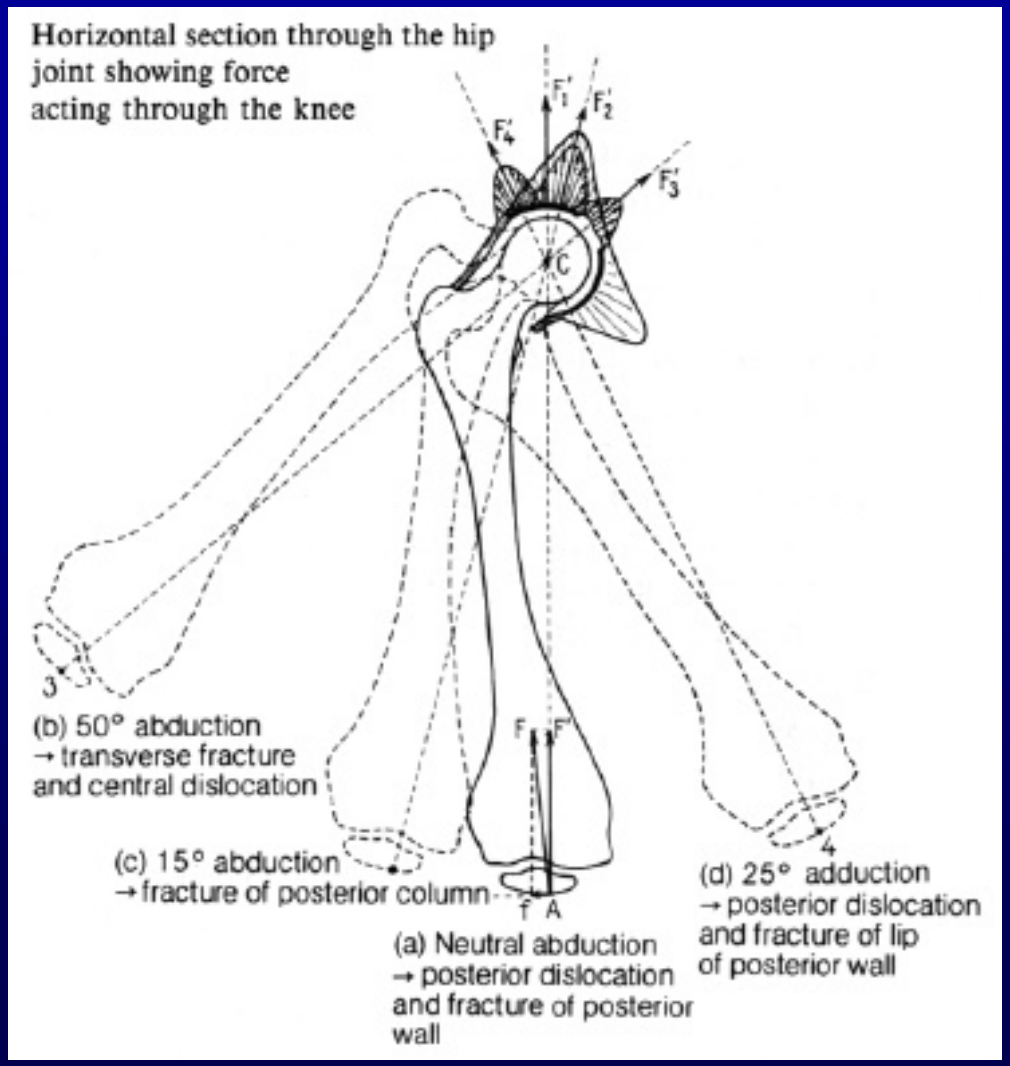
U of M CIREN

Injury Mechanisms

INJURY	CONTACT	MECHANISM
R Frontal Subdural	Hand/Airbag Fling	Acceleration
R Femur	Knee Bolster	Compression (Axis)
L Acetabulum	Knee Bolster	Compression (through femur axis)

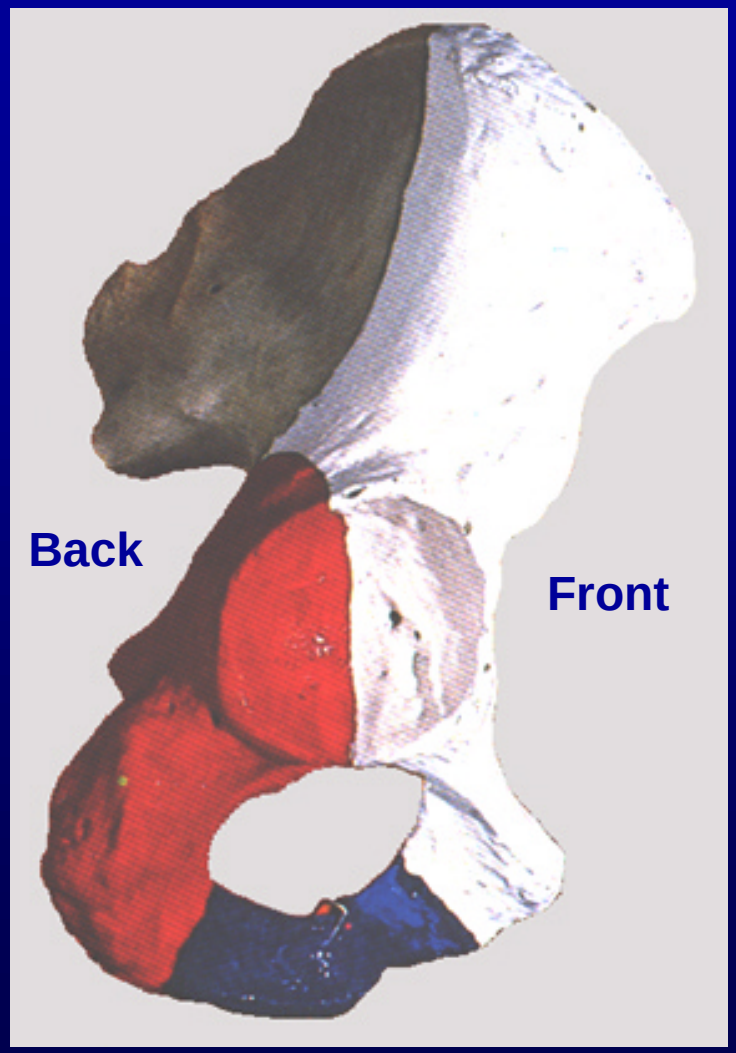


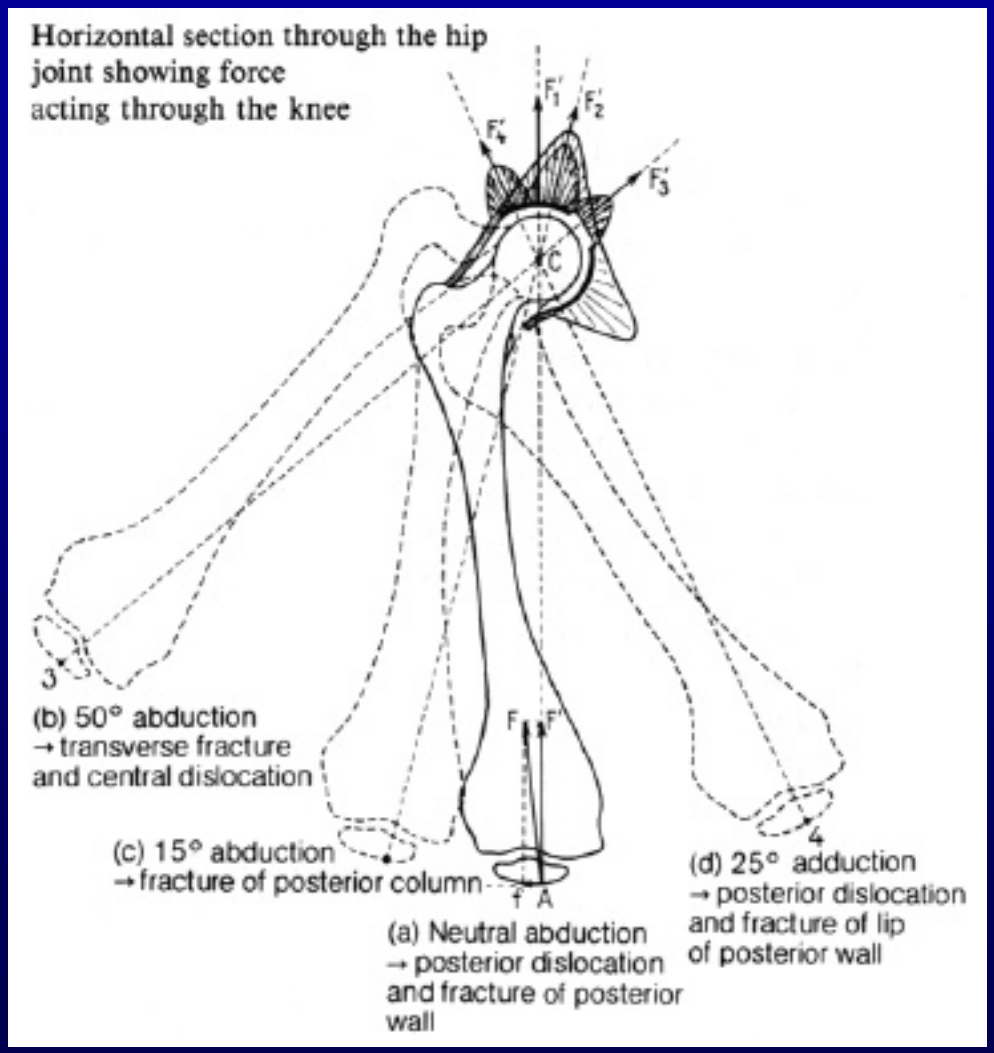
U of M CIREN



Letournel

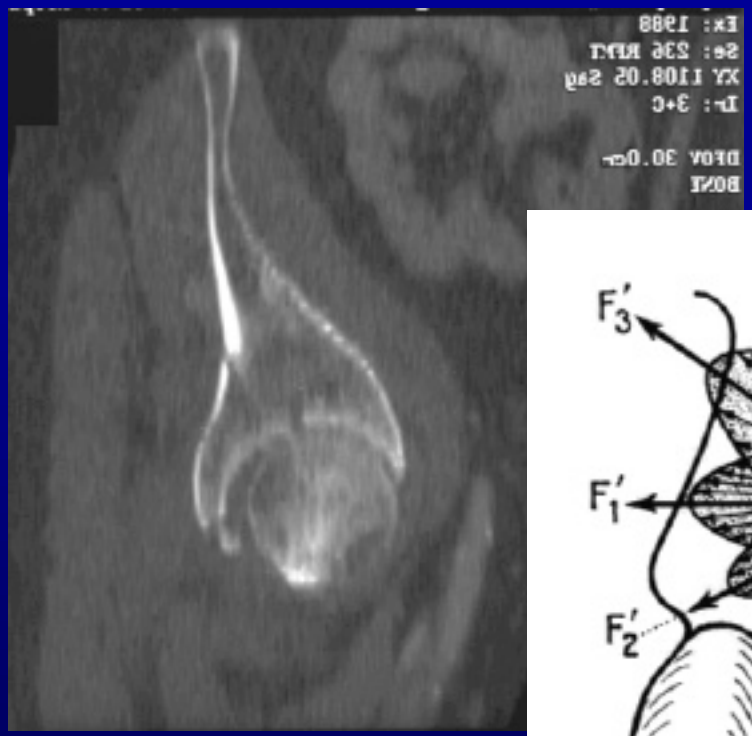
U of M CIREN

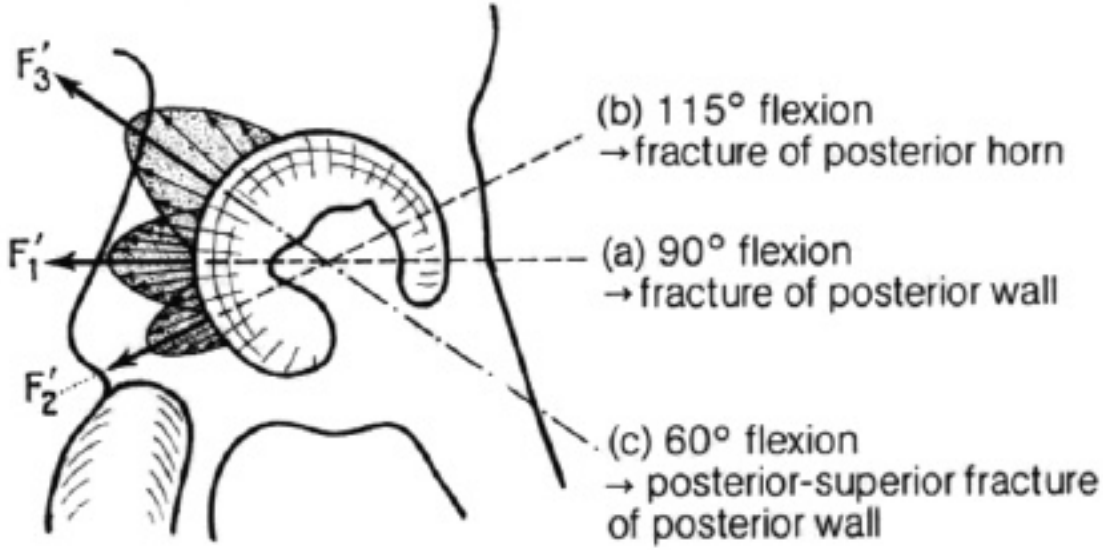




Letournel

U of M CIREN



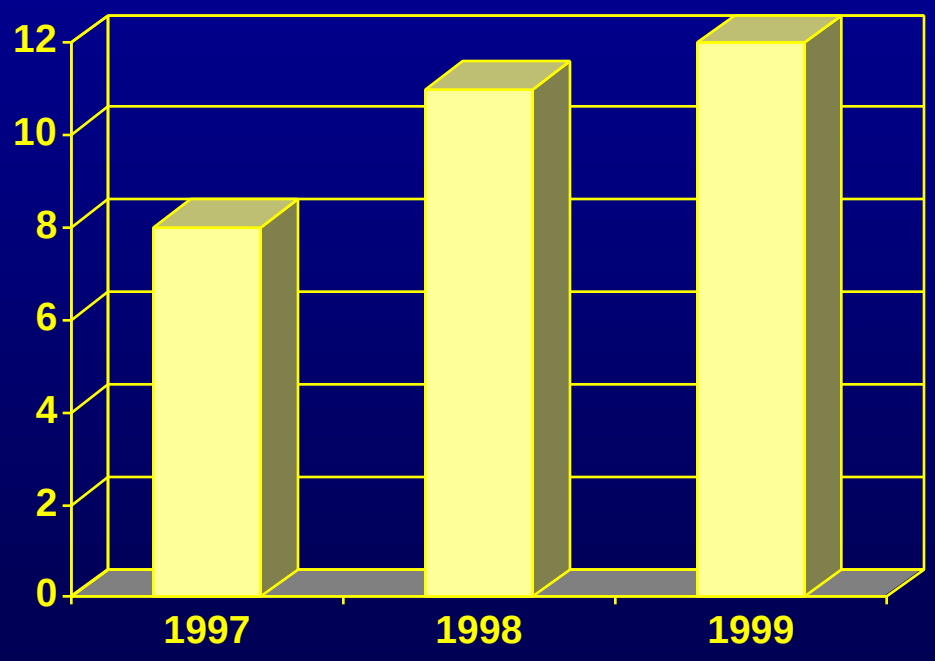


External aspect of hip showing sites of application of force acting through the knee with the hip flexed

Letournel

U of M CIREN

Hip Joint Injuries in Frontal Crashes
Michigan CIREN



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN

U of M CIREN Database Analysis

Patterns of Injuries versus Crash, Vehicle, and Occupant Factors

Independent Variables

- Crash Severity
- Location of Front-End Damage (CDC)
- % Vehicle Overlap
- Rearward Knee bolster Intrusion
- Vehicle Model Year
- Restraint Usage (lap belt)
- Occupant Kinematics
- Occupant Age
- Occupant Location (DR vs. RF)
- Occupant Gender

Dependent Variables

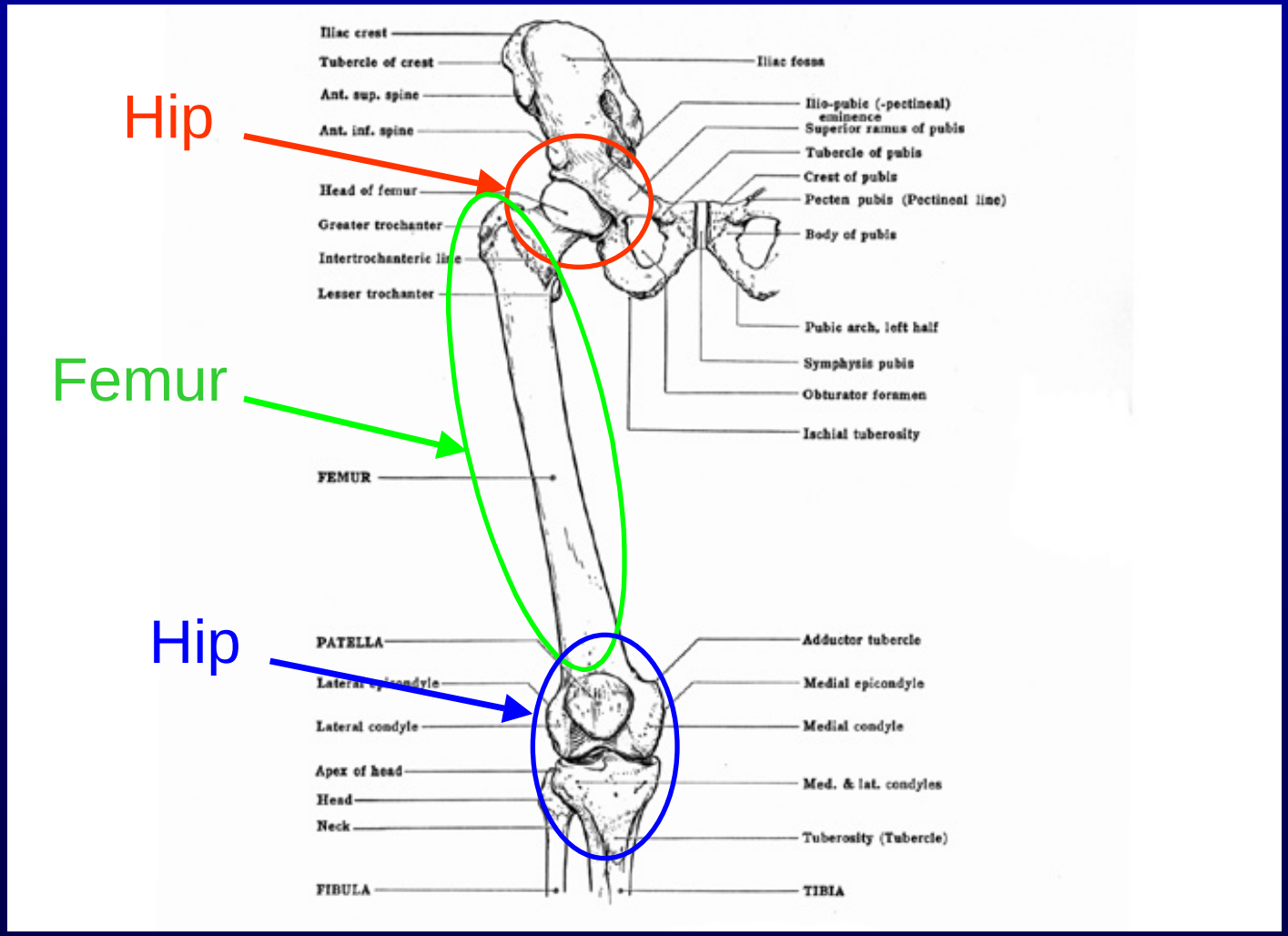
- Hip Fractures/Dislocations
- Femur Fractures
- Knee Fractures
- Side of body injured

Fractures and Dislocations of the Knee-Thigh-Hip Complex in Frontal Crashes

U of M CIREN Database

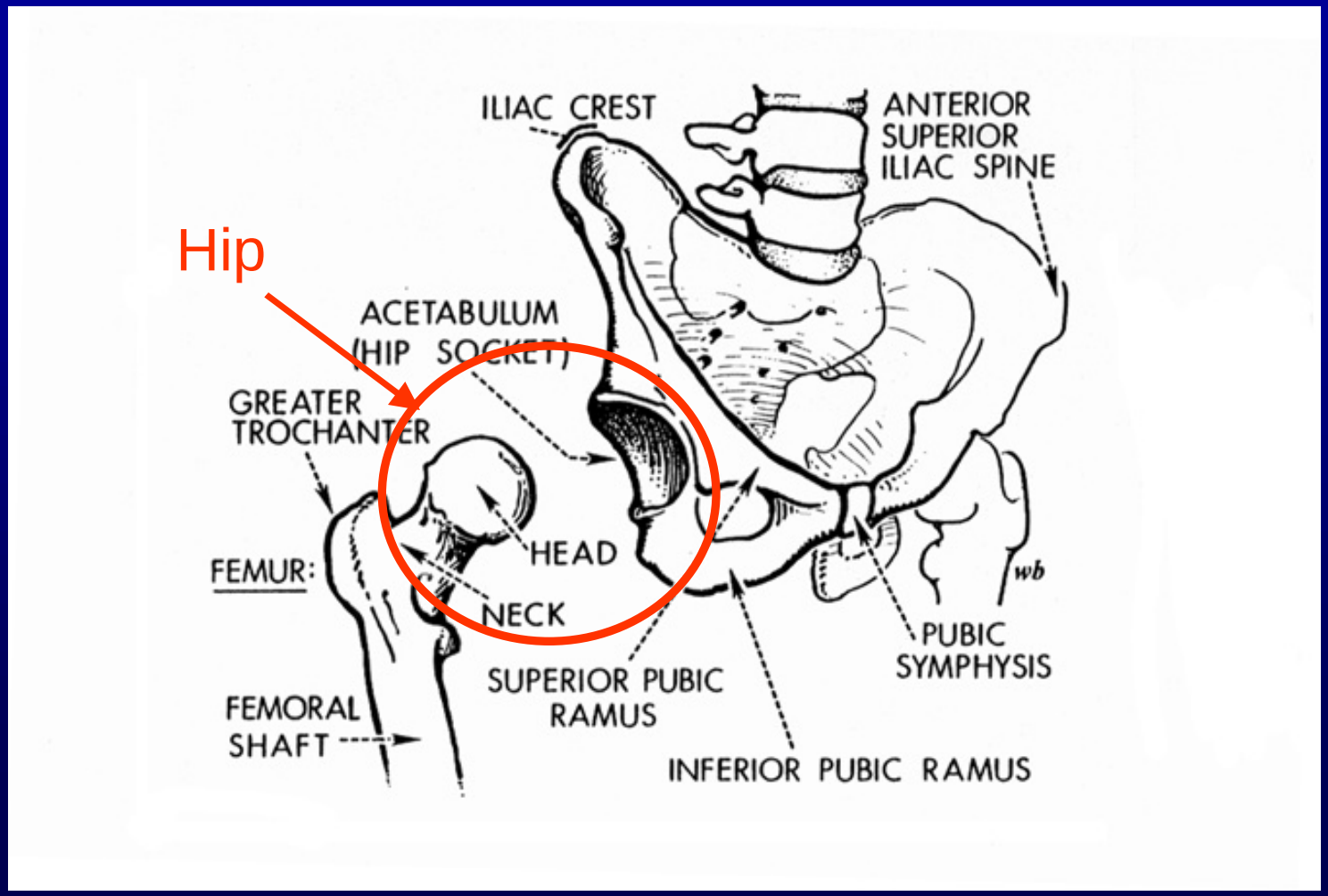
- as of 8/31/99
  - 49 case occupants with KTH fractures/dislocations
- as of 5/5/00
  - 57 case occupants with KTH fractures/dislocations

Fractures and Dislocations of the Knee-Thigh-Hip Complex in Frontal Crashes



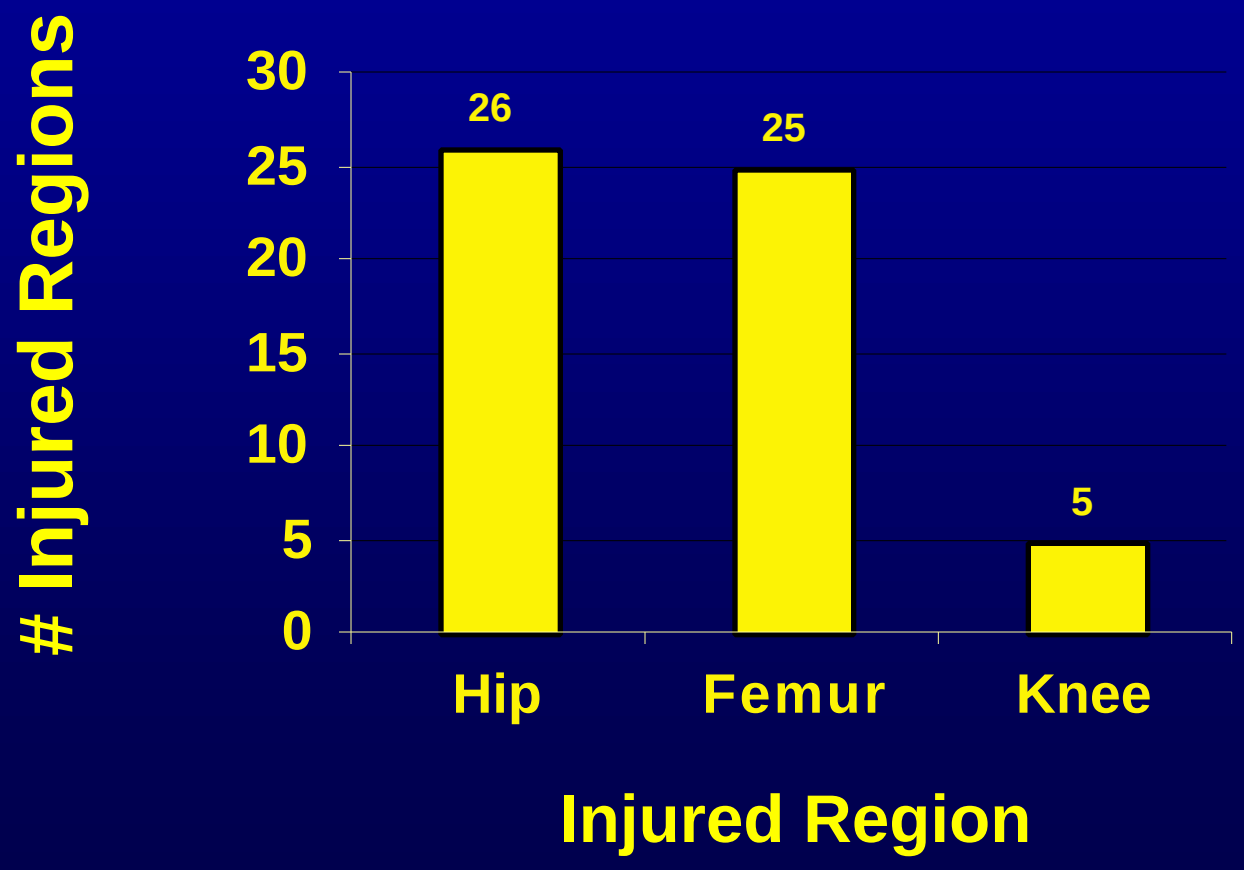
U of M CIREN

Fractures and Dislocations of the Hip



K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

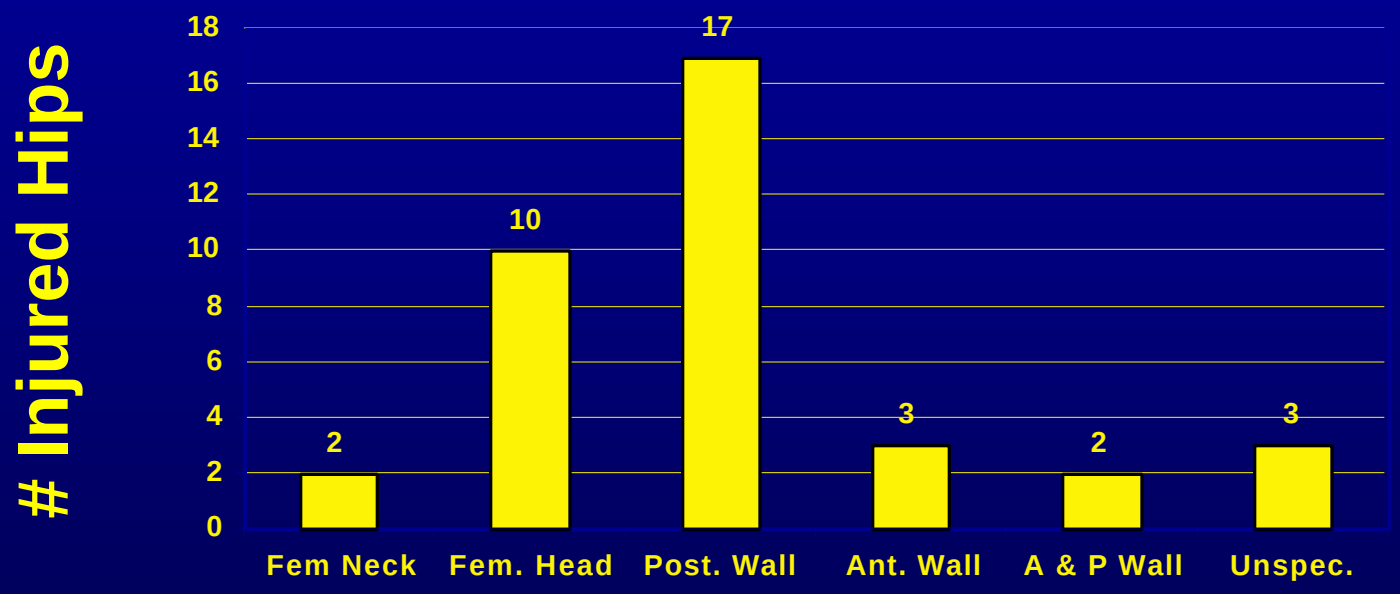
Distribution of Injured Body Regions (N = 56)



U of M CIREN

Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

Distribution of Hip Fractures

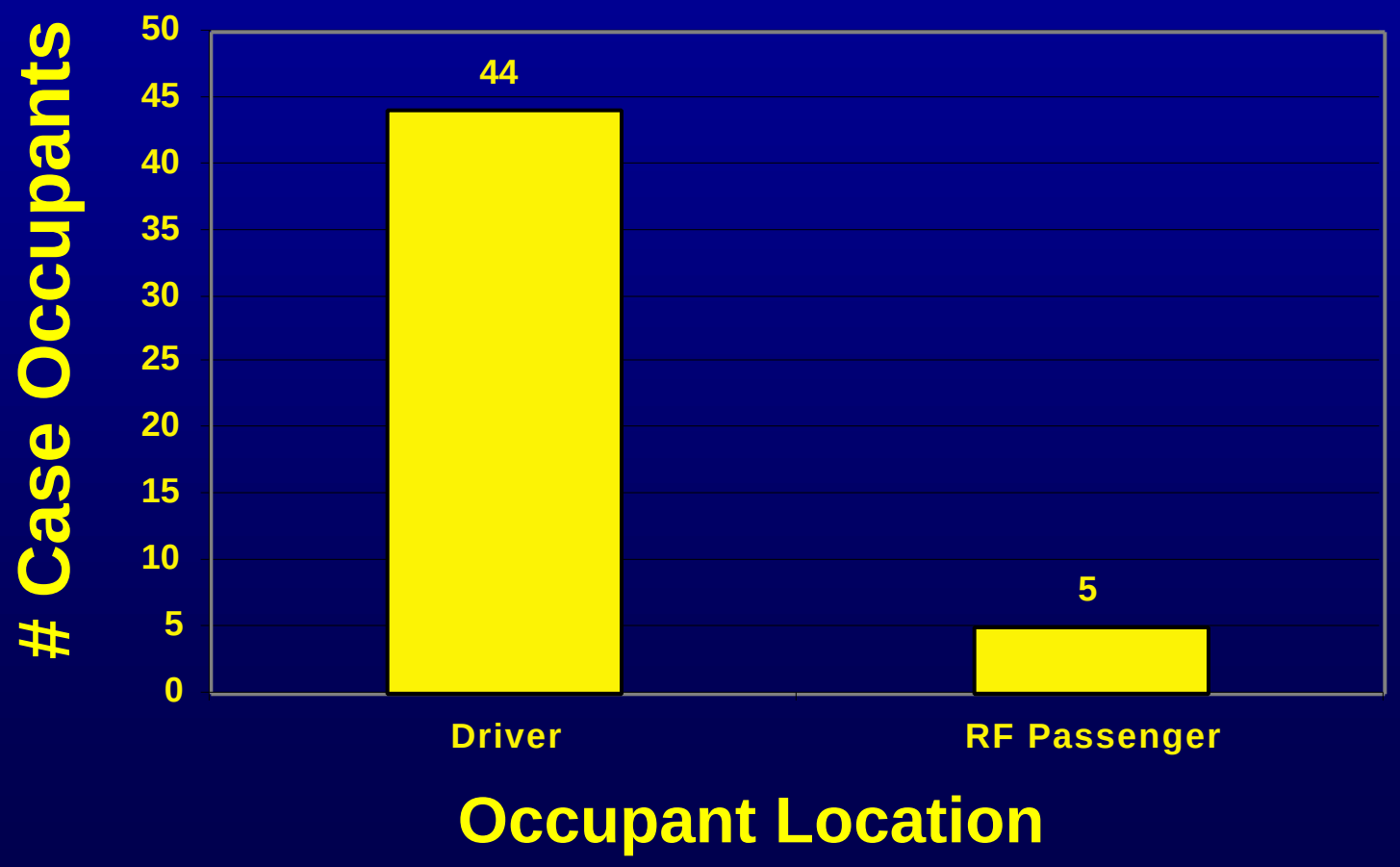


Location of Hip Fracture/Dislocation

U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

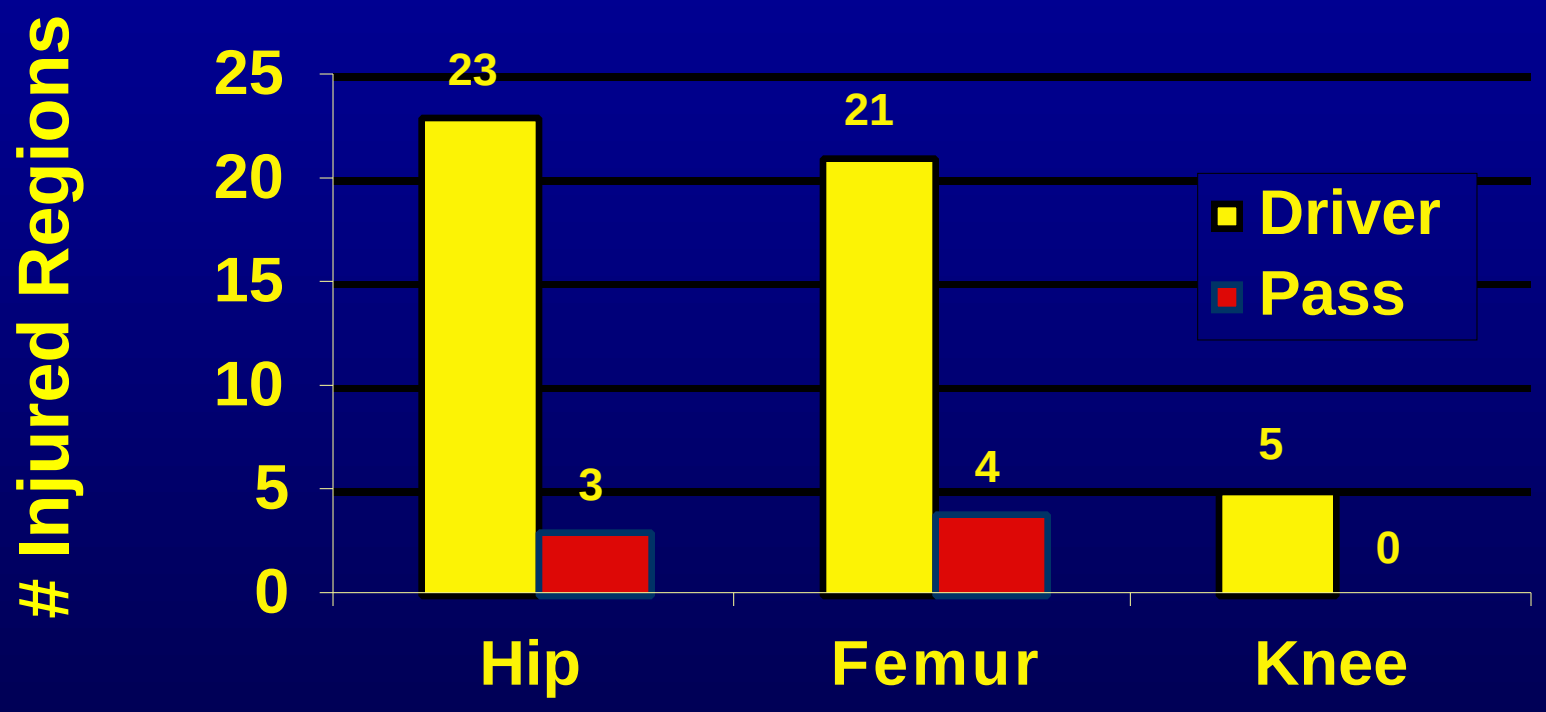
Distribution of Injured Occupant Location



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

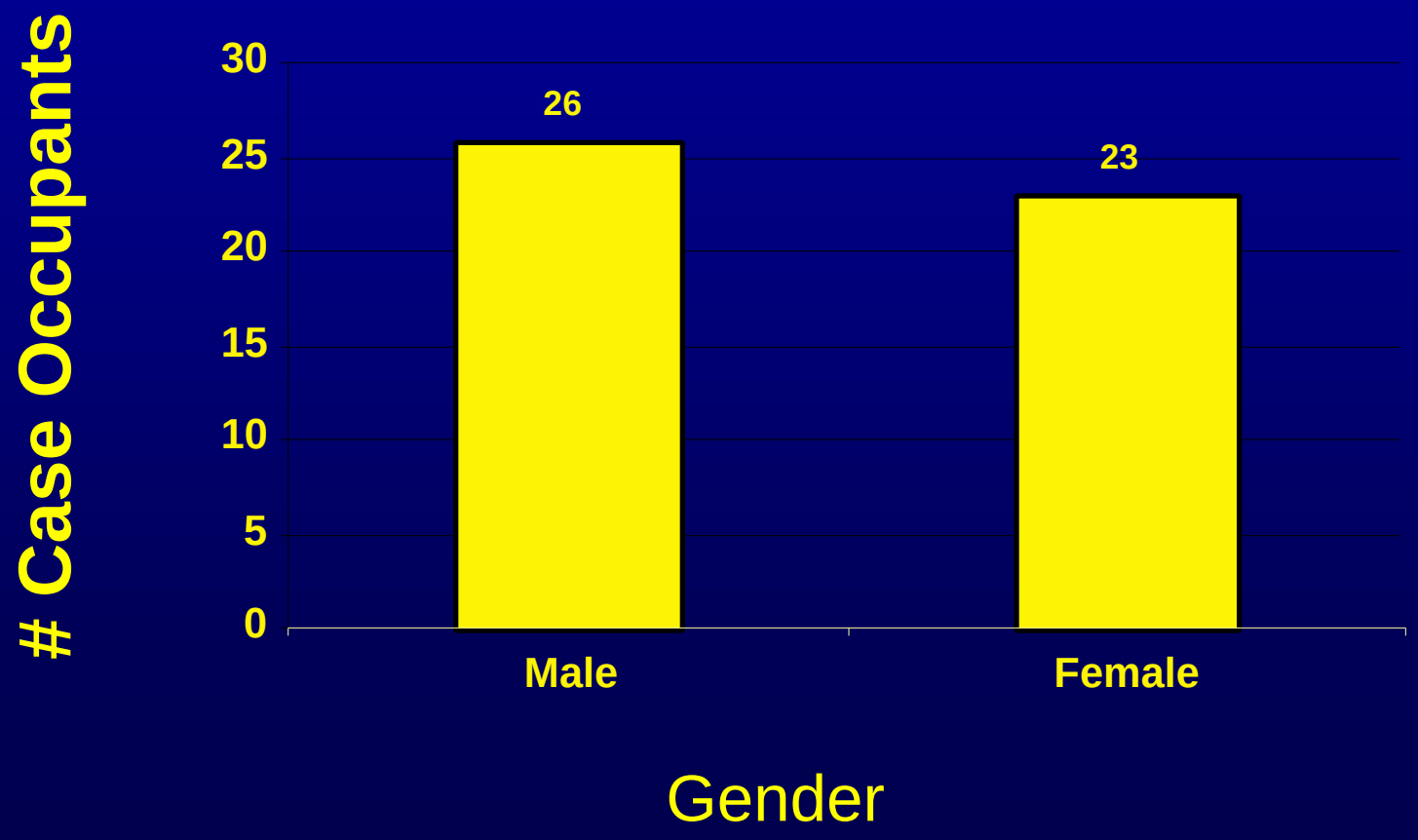
Distribution of Occupant Location by Injured Region



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

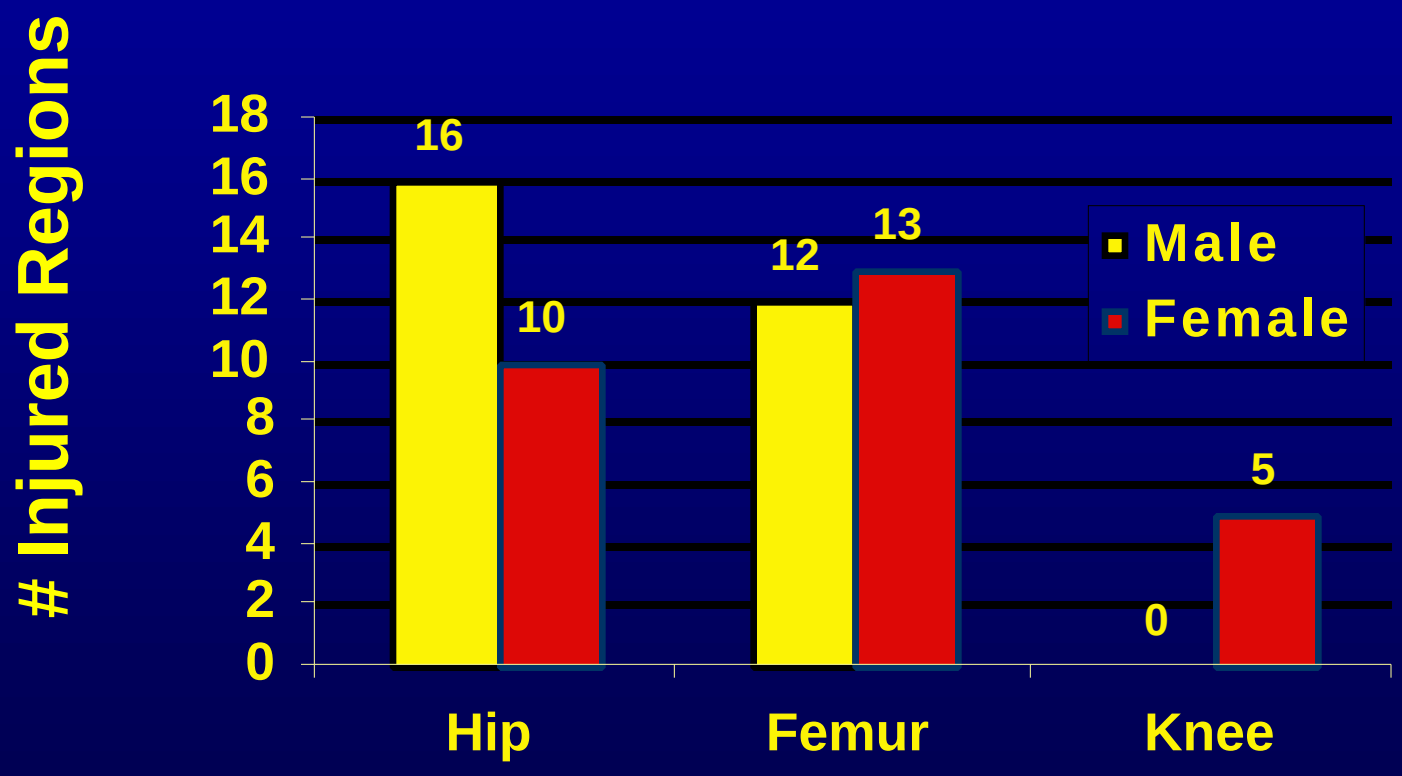
Distribution of Injured Occupant Gender



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Occupant Gender by Injured Region

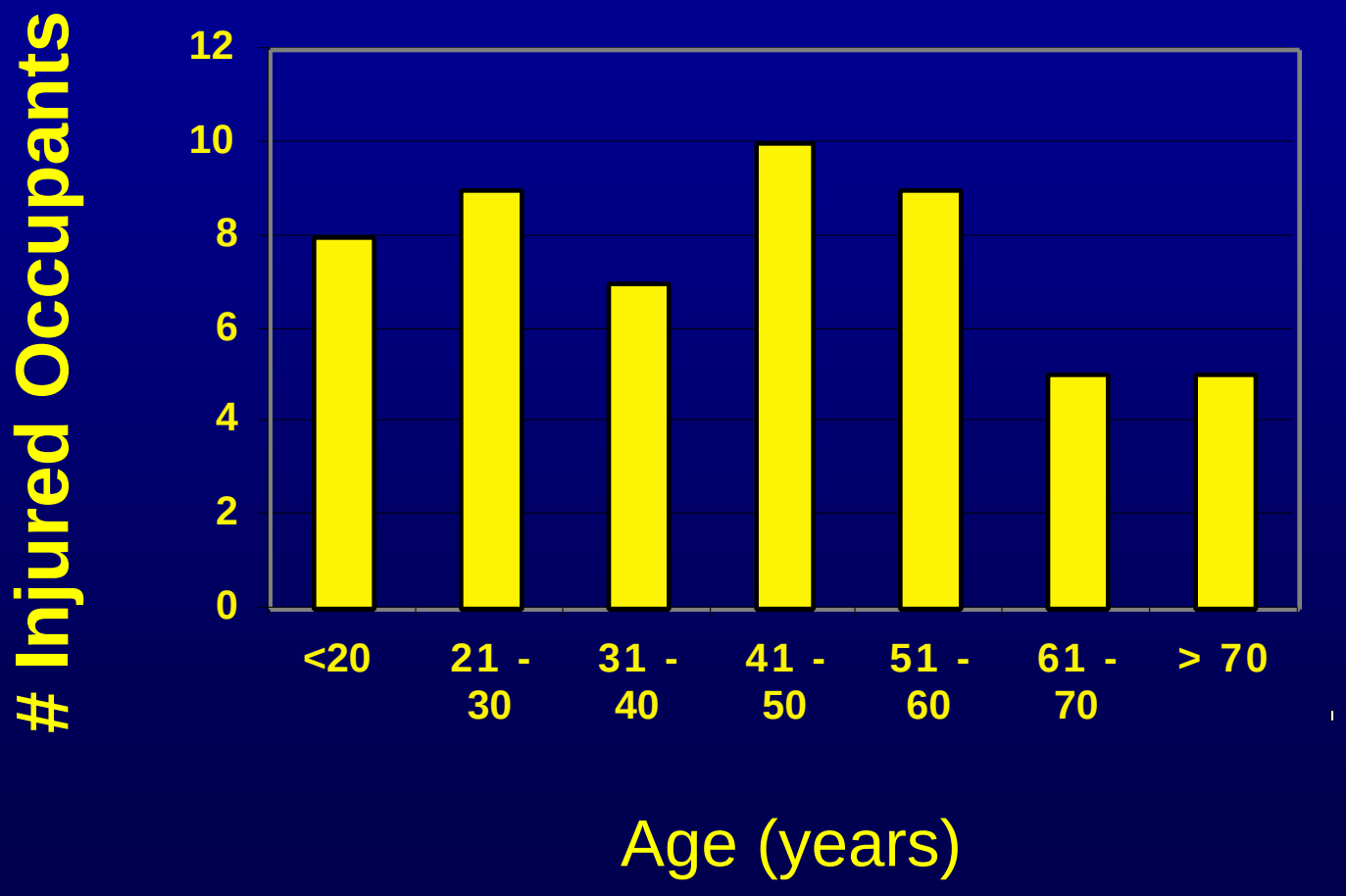


Gender by Injured Region

U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 5/5/00

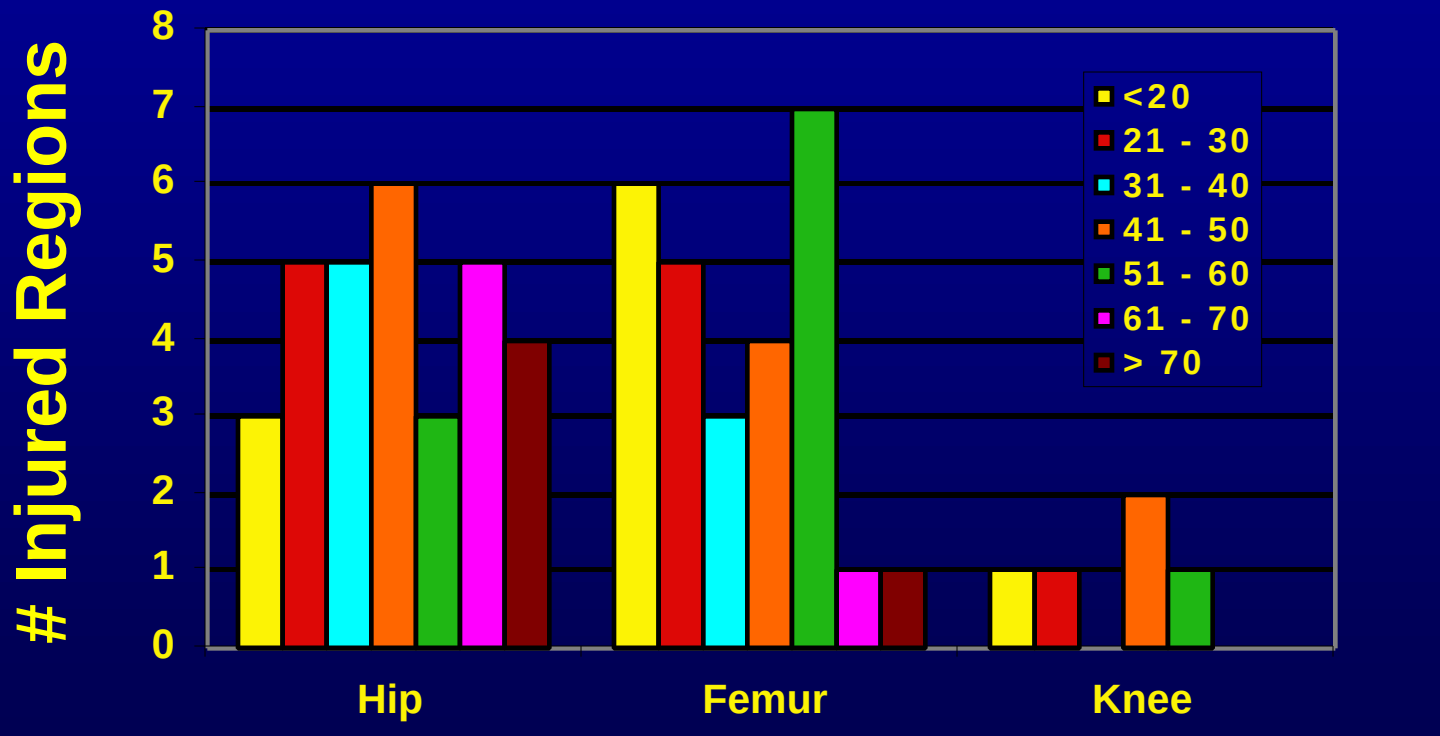
Distribution of Injured Occupant Age



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 5/5/00

Distribution of Occupant Age by Injured Region

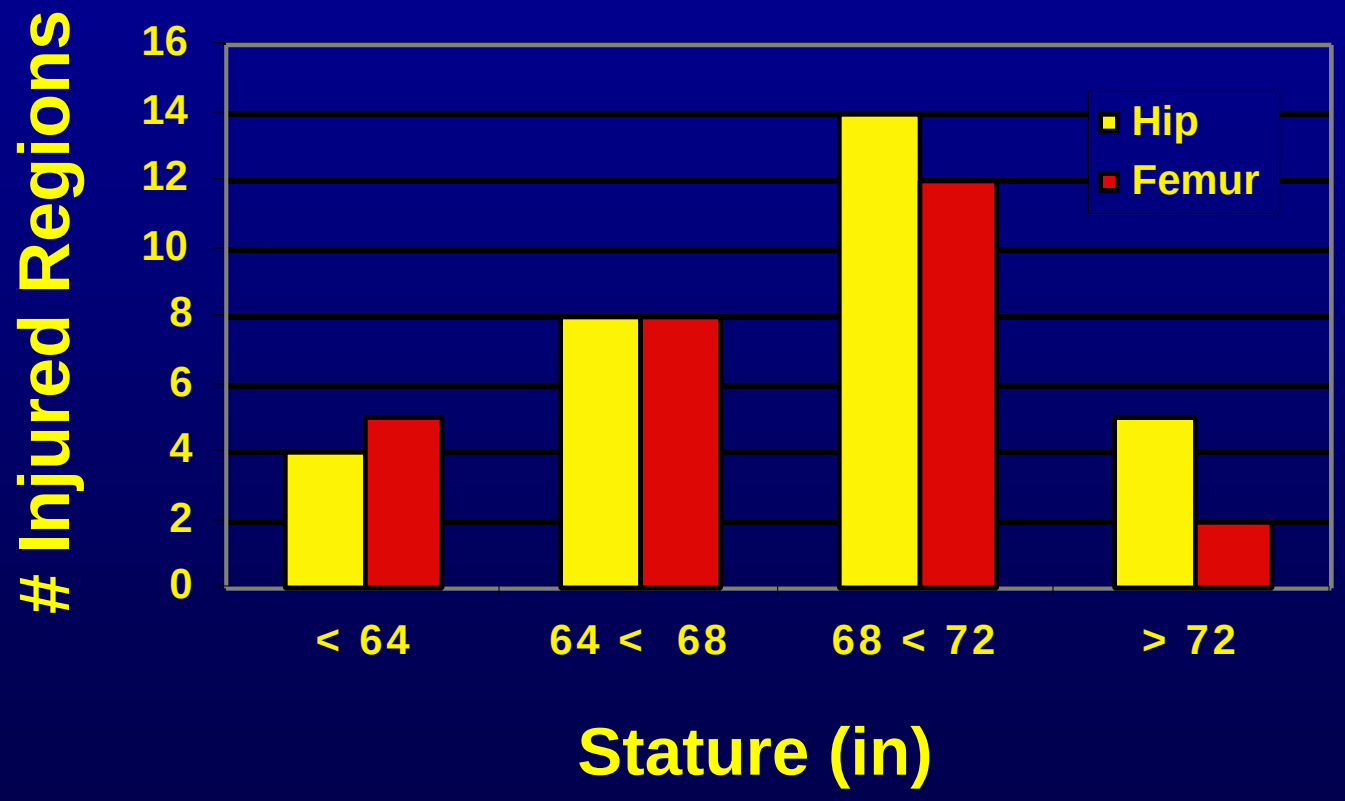


Age Group in Years by Injured Region

U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 5/5/00

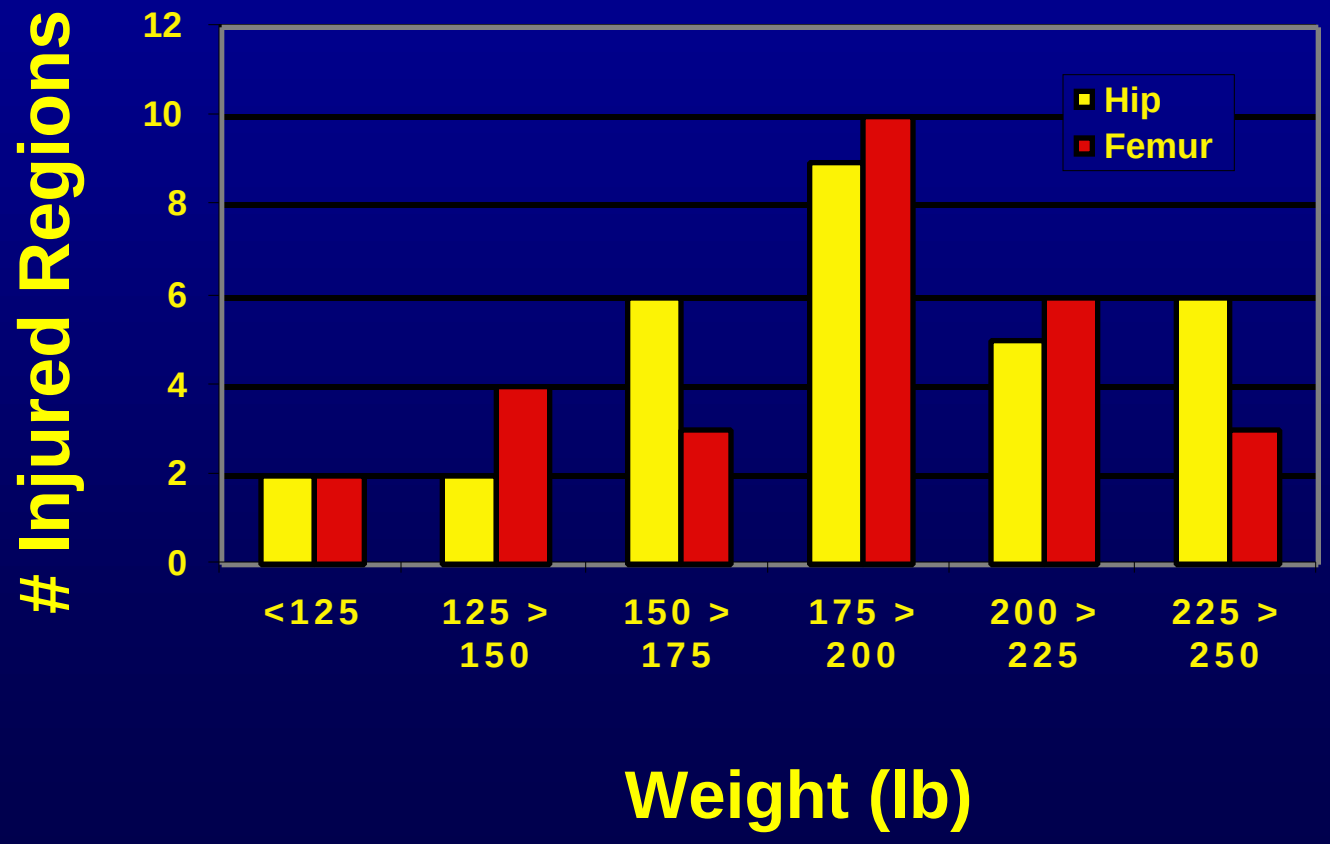
Distribution of Hip an Femur Fx/Dislocations by Injured Occupant Stature



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 5/5/00

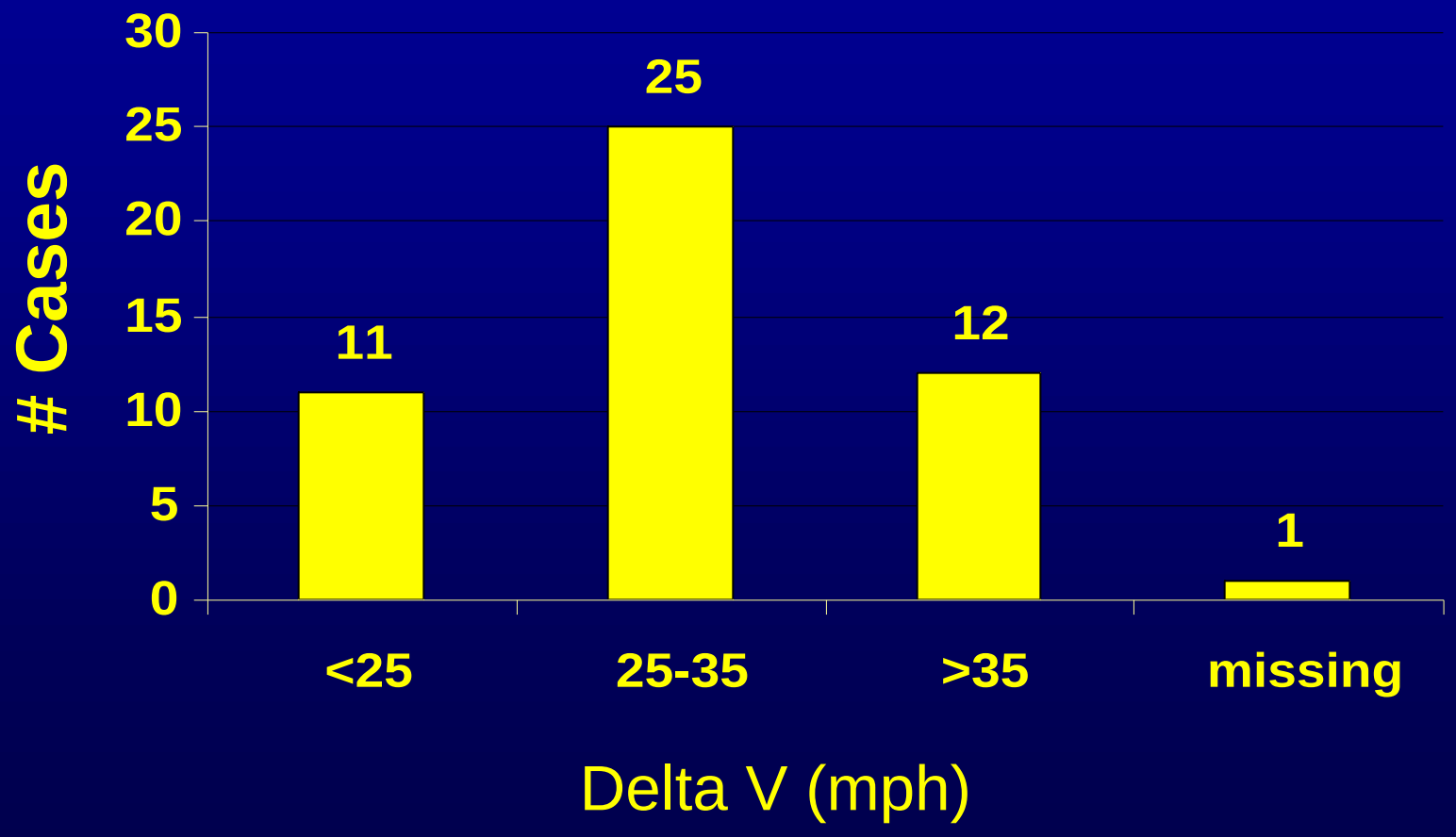
Distribution of Hip and Femur Fx/Dilocations by Injured Occupant Weight



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

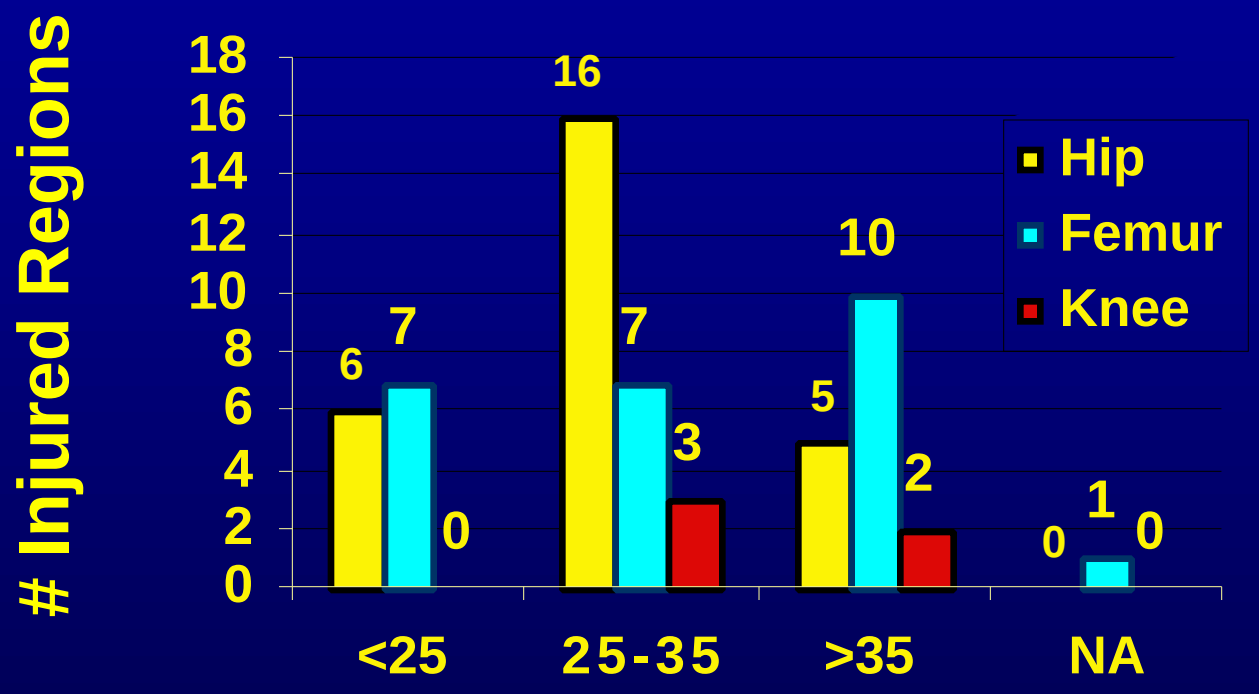
Distribution of Delta V for Injured Occupant Frontal Crashes



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

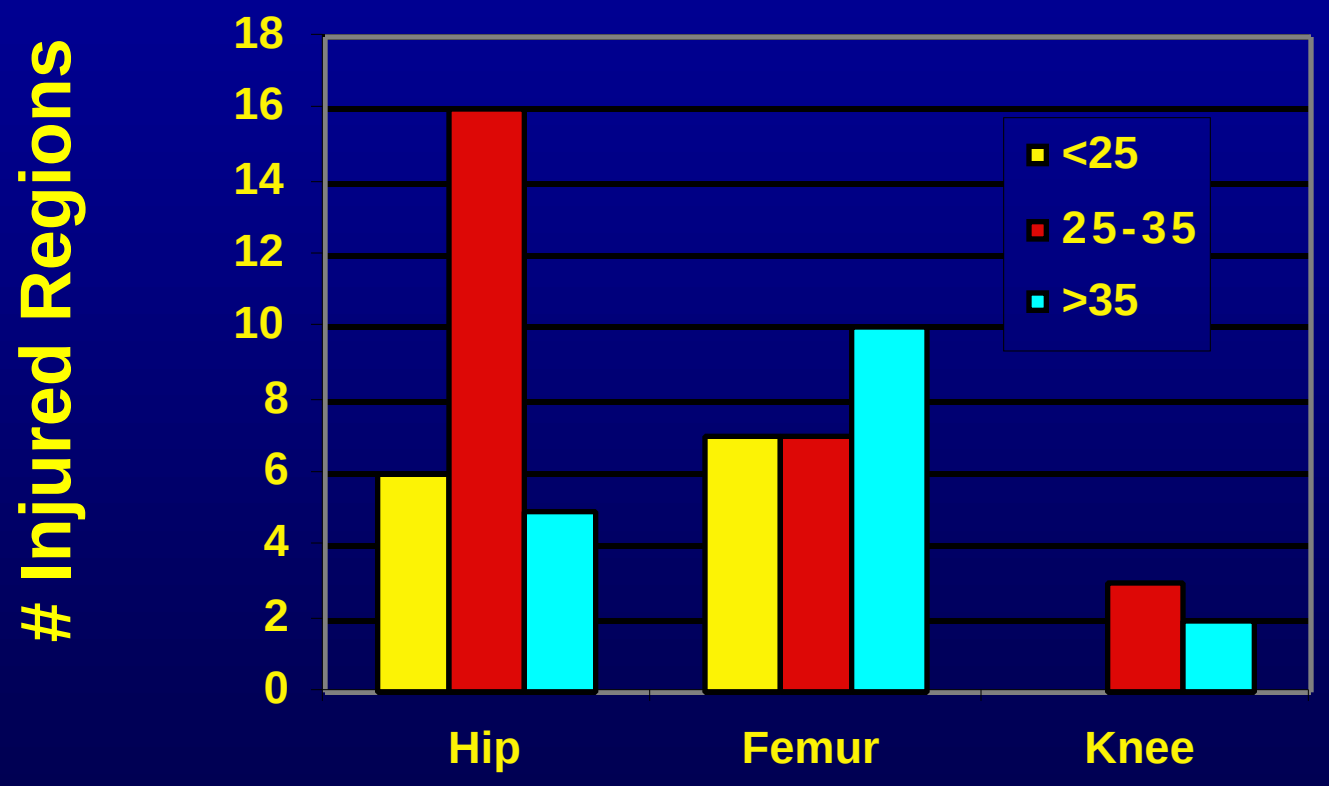
Distribution of Injured Regions by Delta V



Injured Region by Delta V (mph)

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Delta V by Injured Region

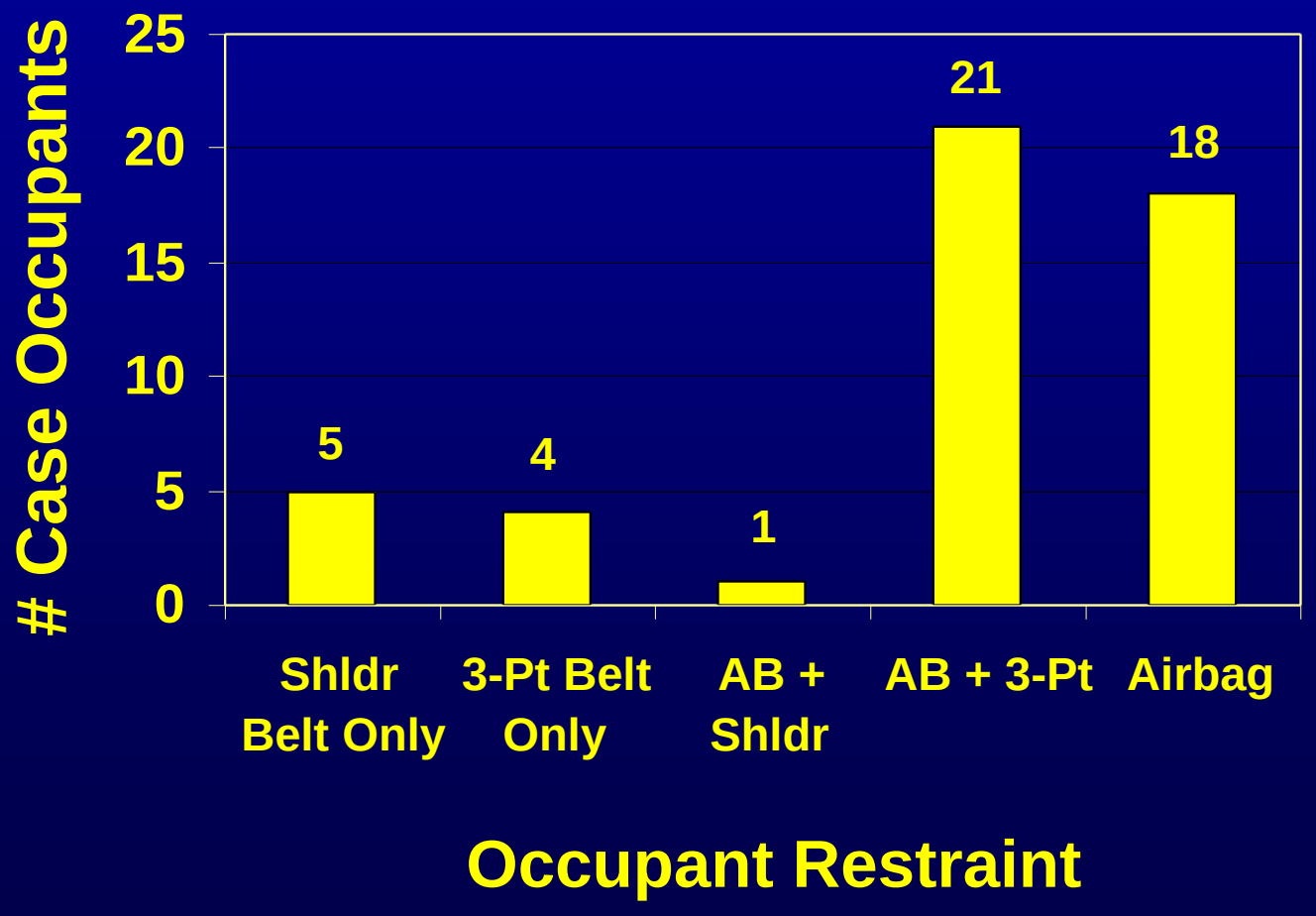


Delta V (mph) by Injured Region

U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

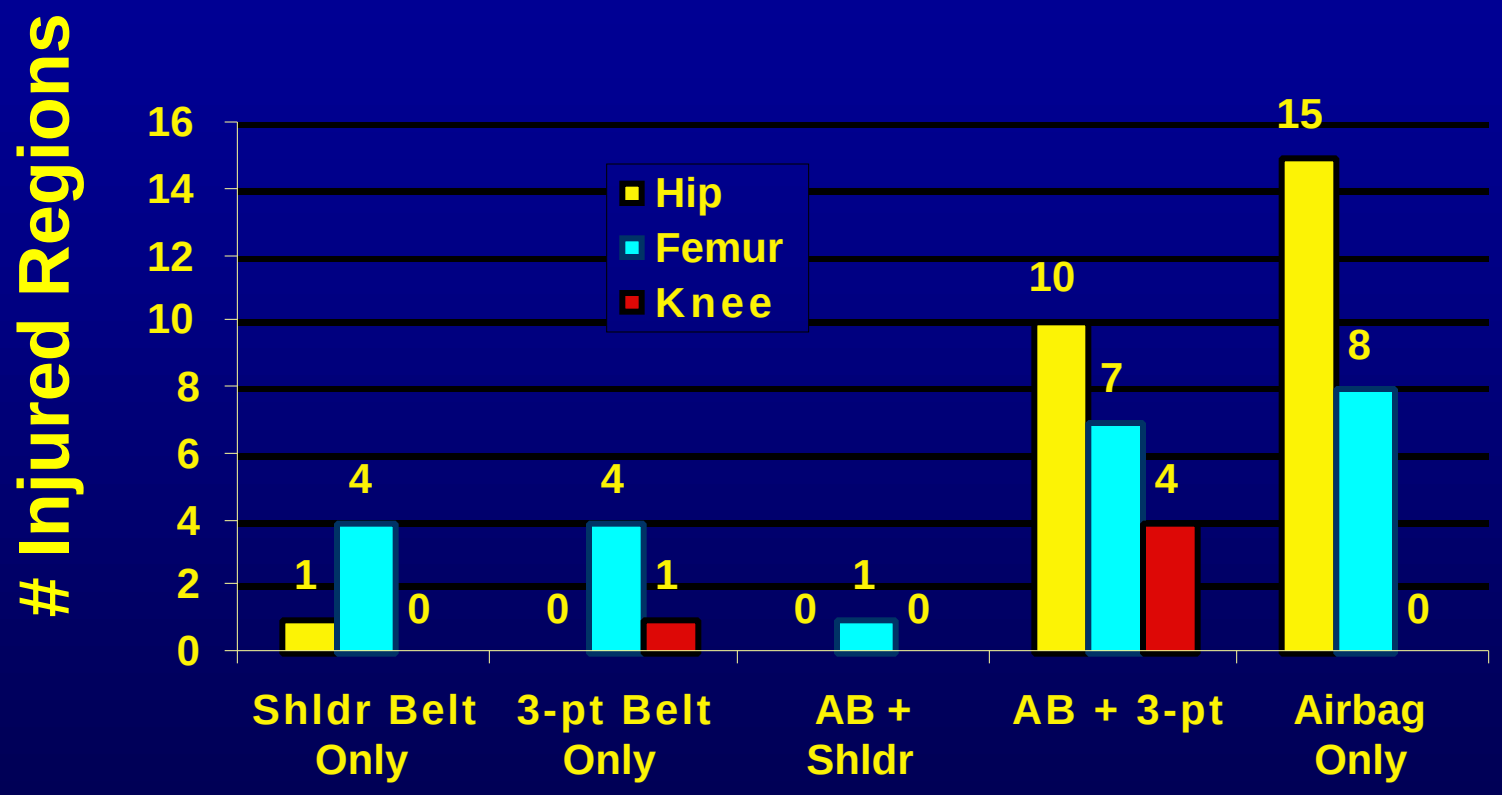
Distribution of Injured Occupant Restraint Usage



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of Injured Region by Restraint Usage

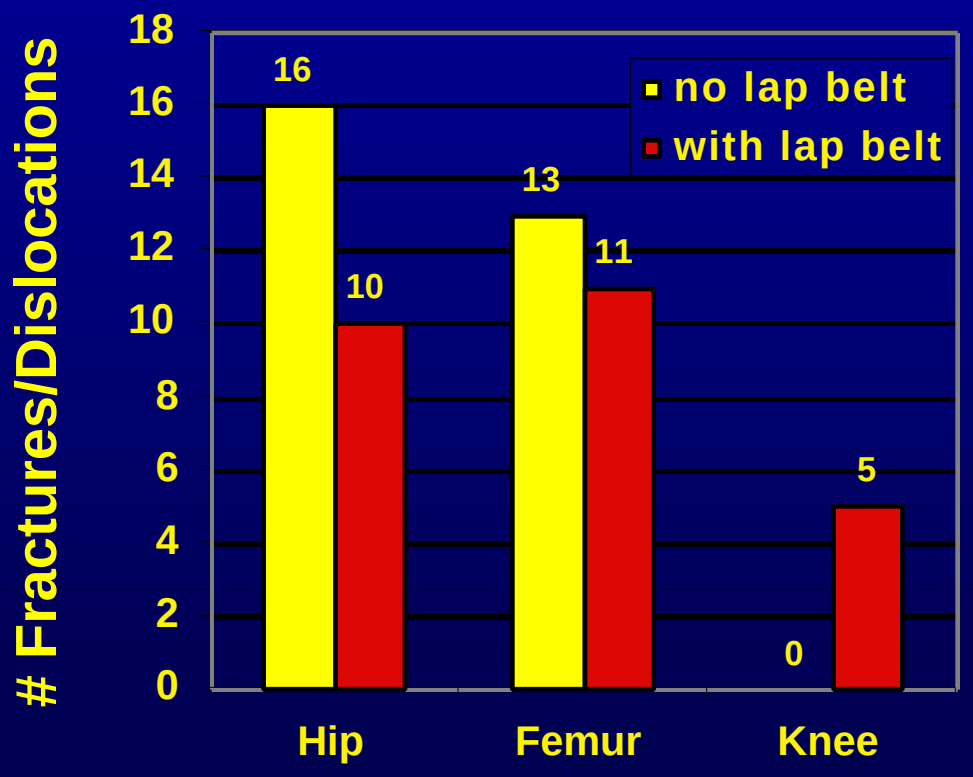


Injured Region by Injured Occupant Restraint

U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

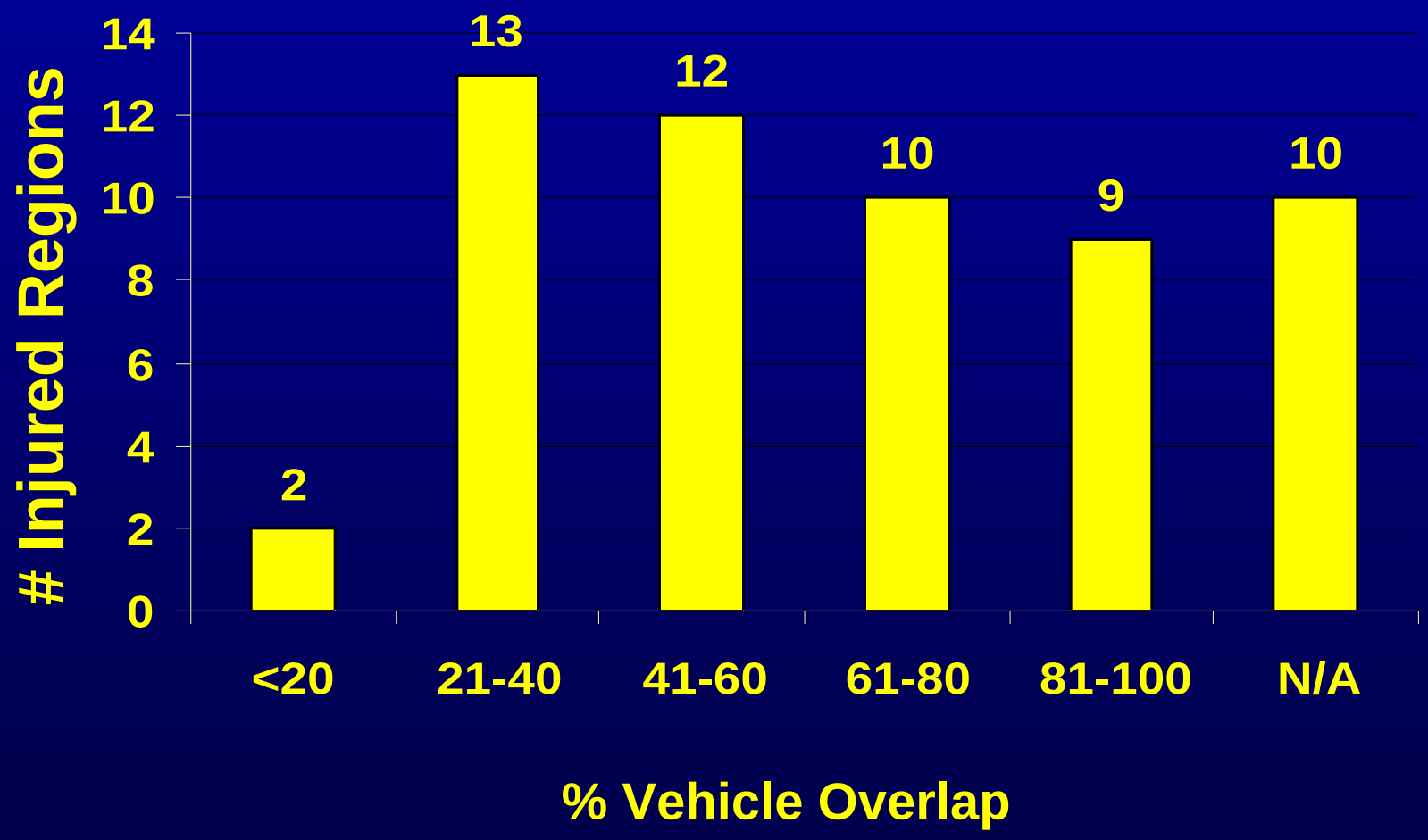
Distribution of Fracture/Dislocations by Lap Belt Usage



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

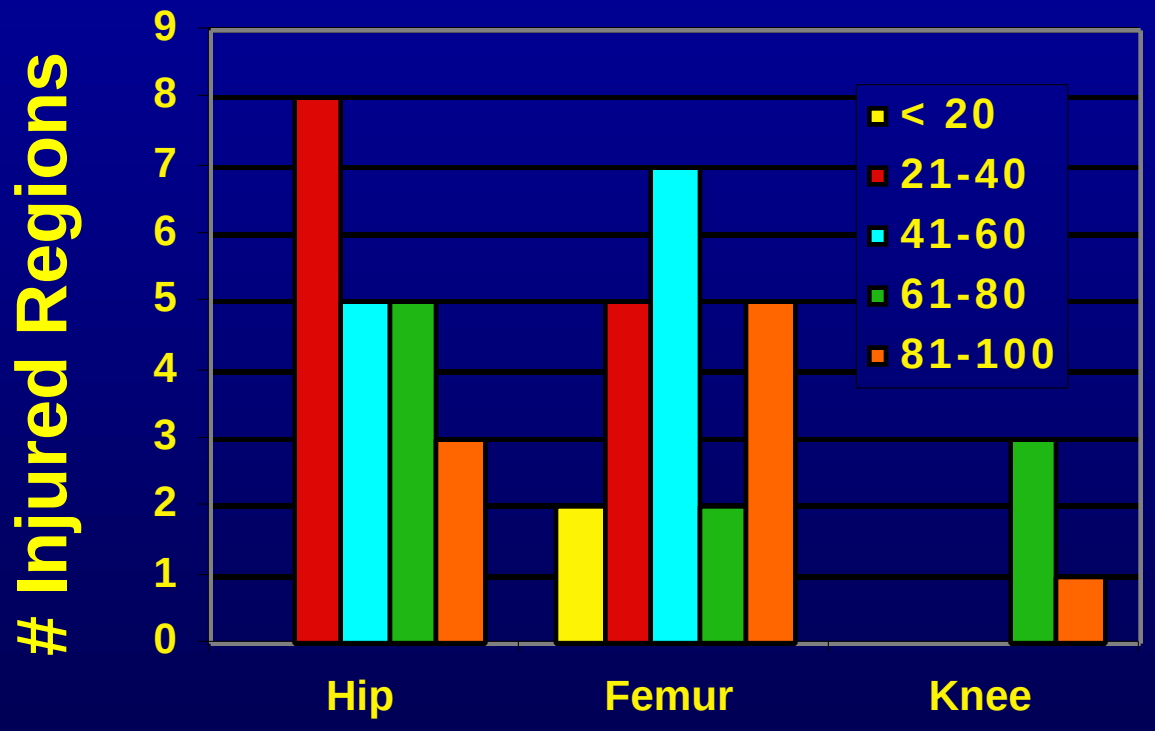
Distribution of % Vehicle Overlap for Injured Occupant Frontal Crashes



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution of %Vehicle Overlap by Injured Region

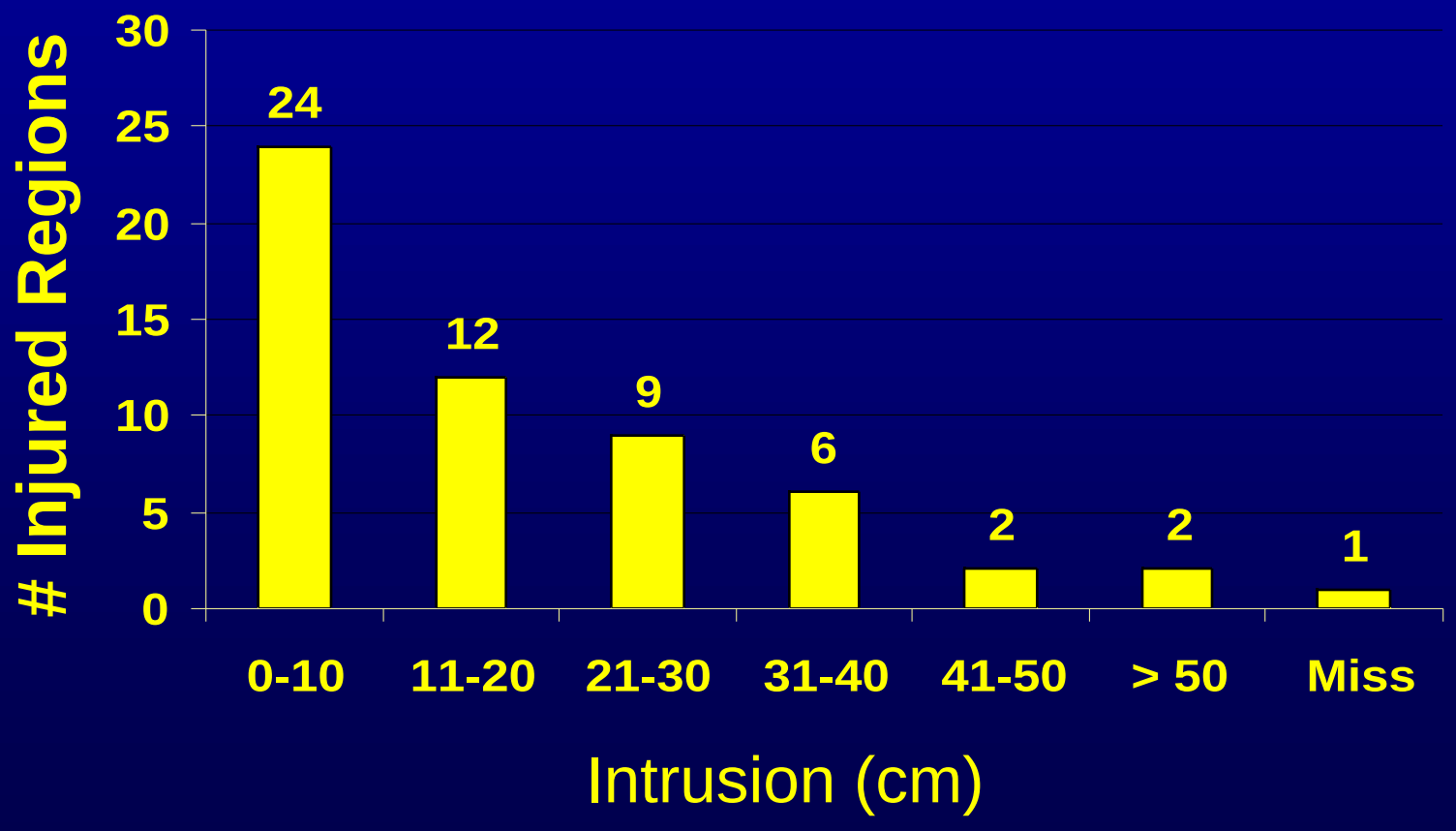


% VOL by Injured Region

U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

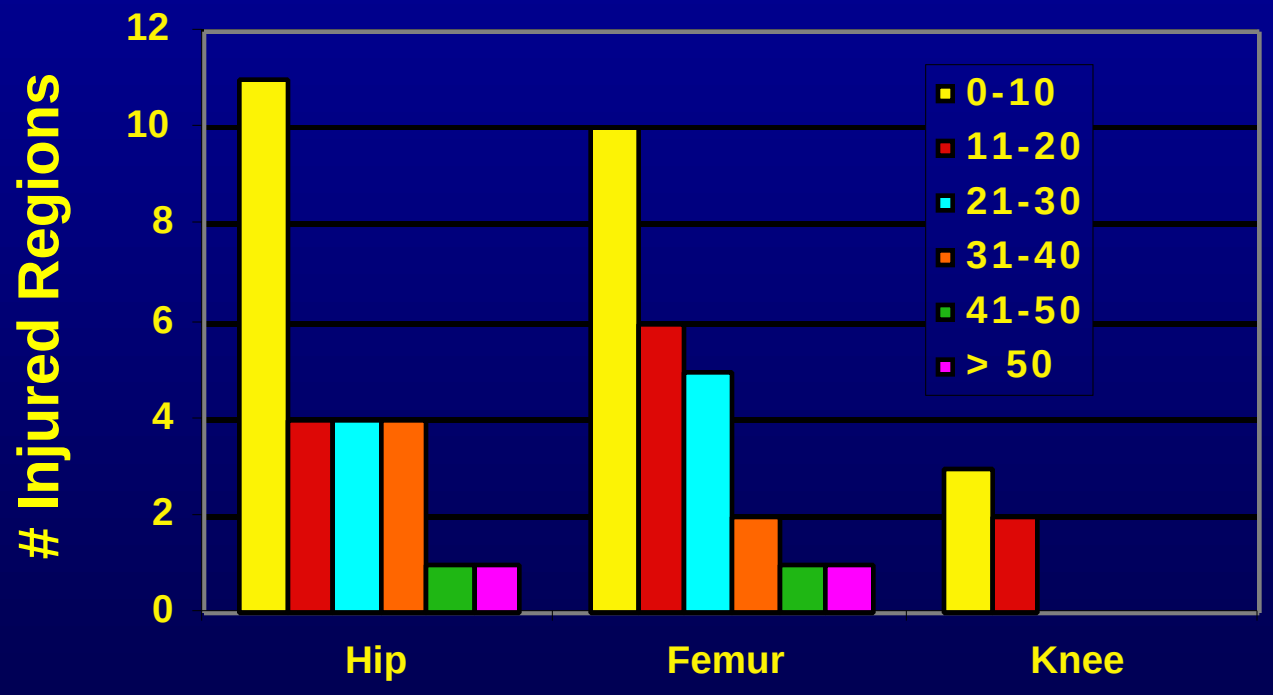
Distribution of IP/Knee-Bolster Rearward Intrusion for Injured Occupant Frontal Crashes



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

Distribution IP/Knee-Bolster Rearward Intrusion by Injured Region

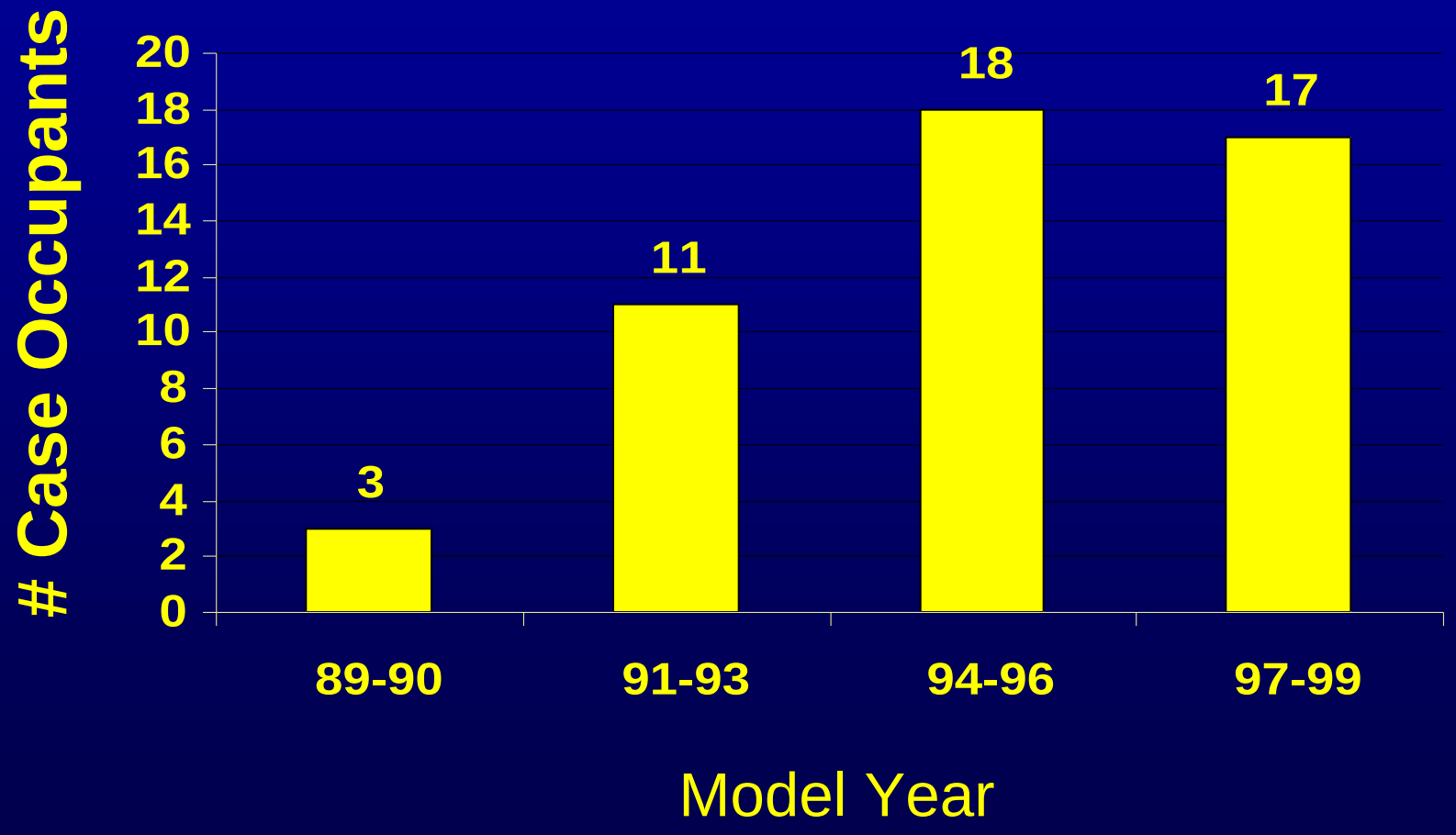


Rearward Intrusion in cm by Injured Region

U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

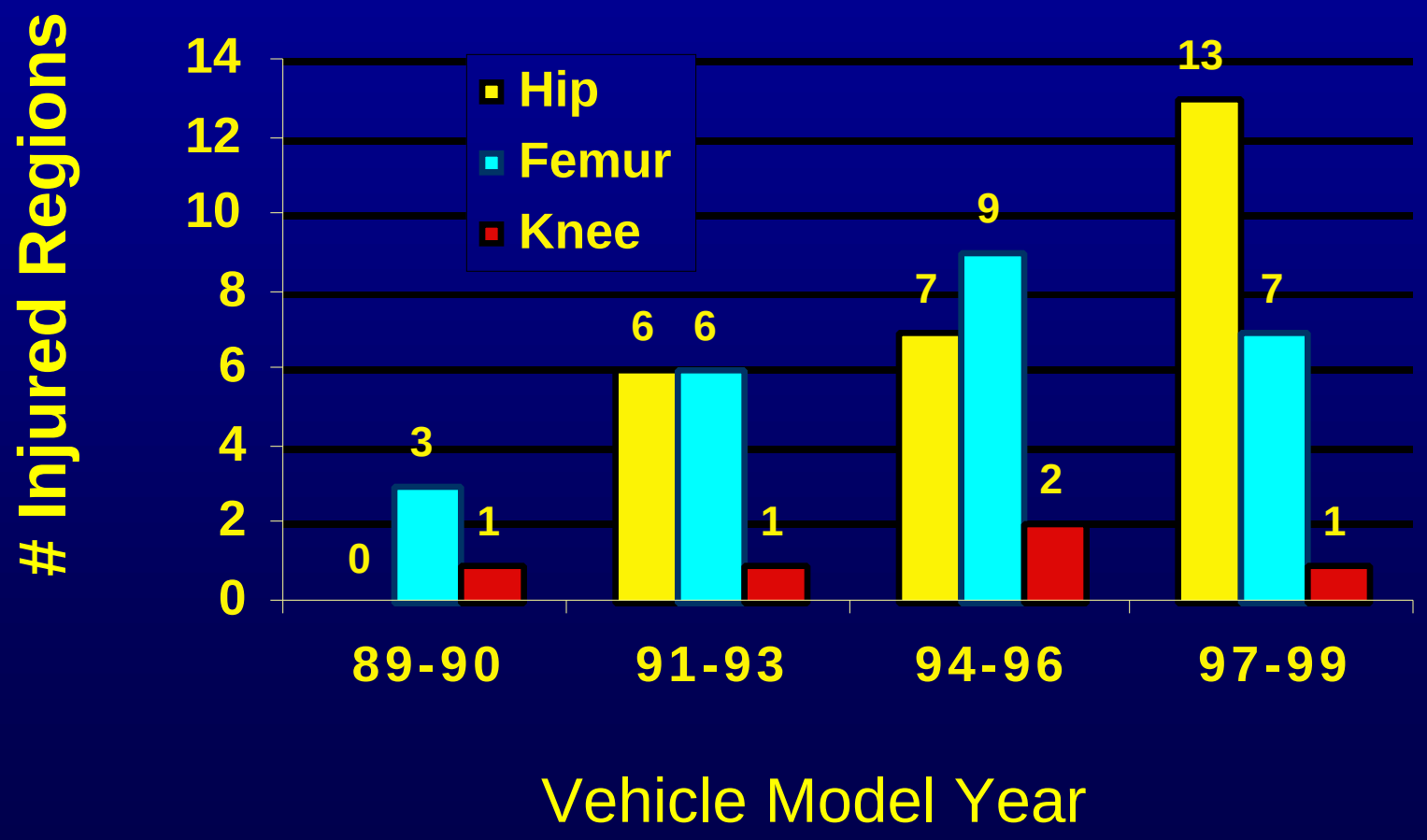
Distribution of Vehicle Model Year for Injured Occupant Frontal Crashes



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

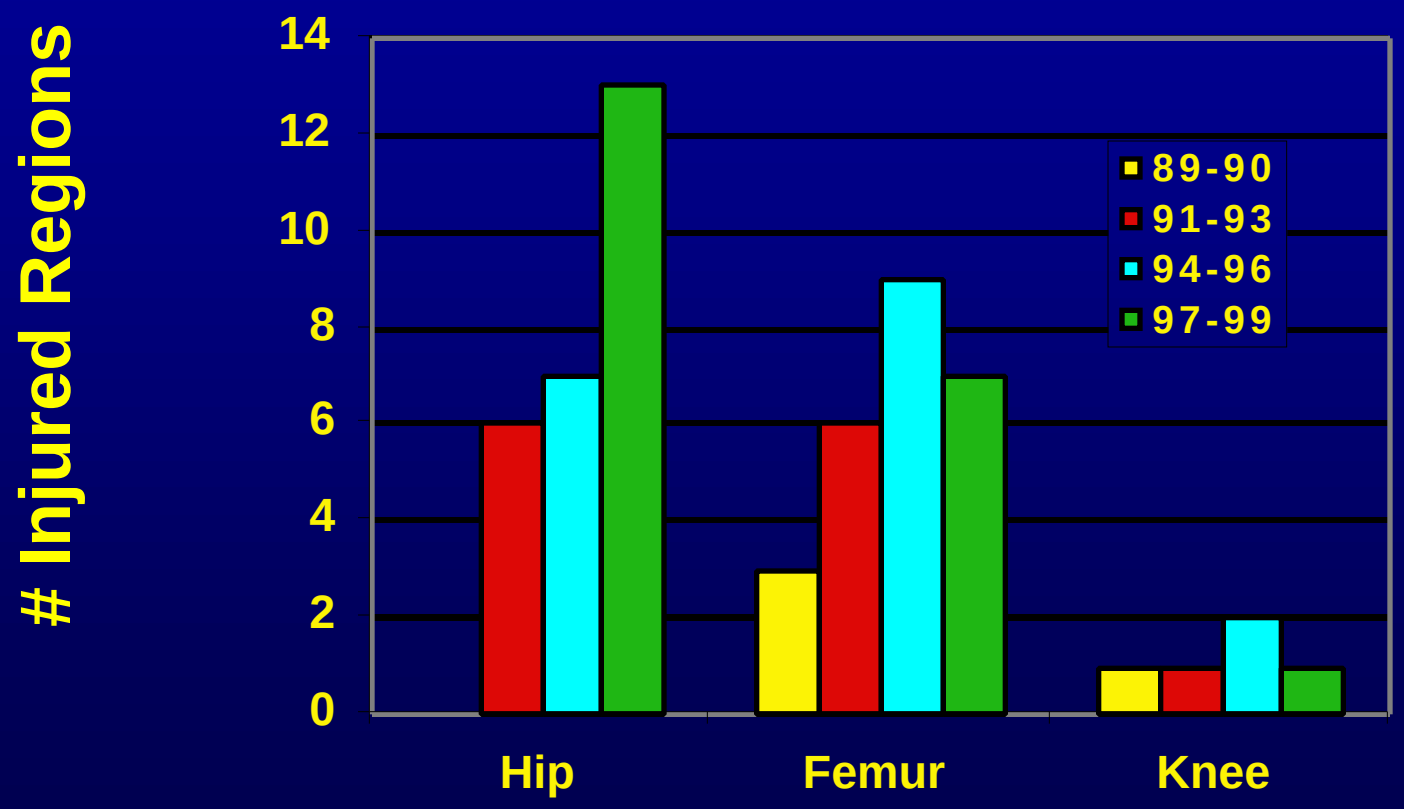
Distribution of Injured Regions by Vehicle Model Year



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

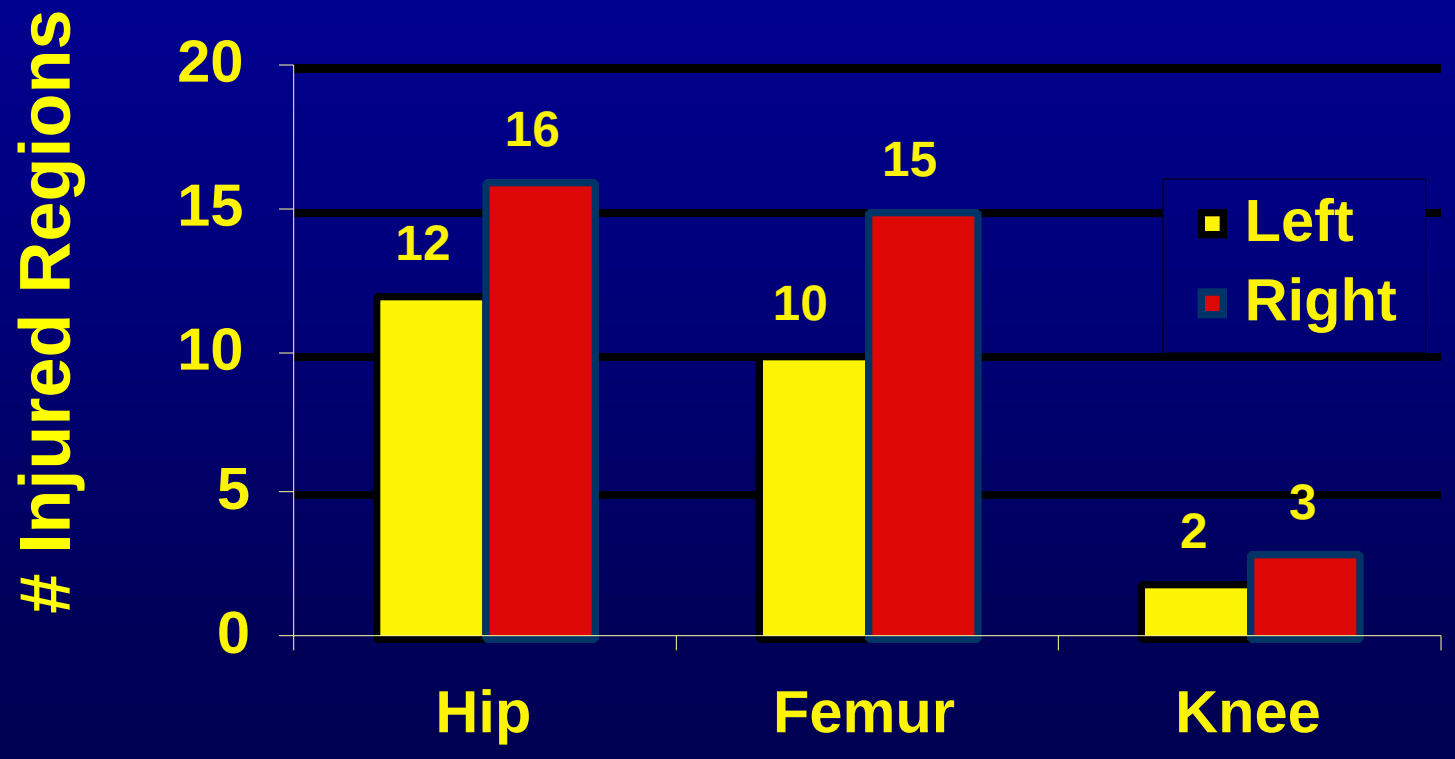
Distribution of Vehicle Model Year by Injured Region



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

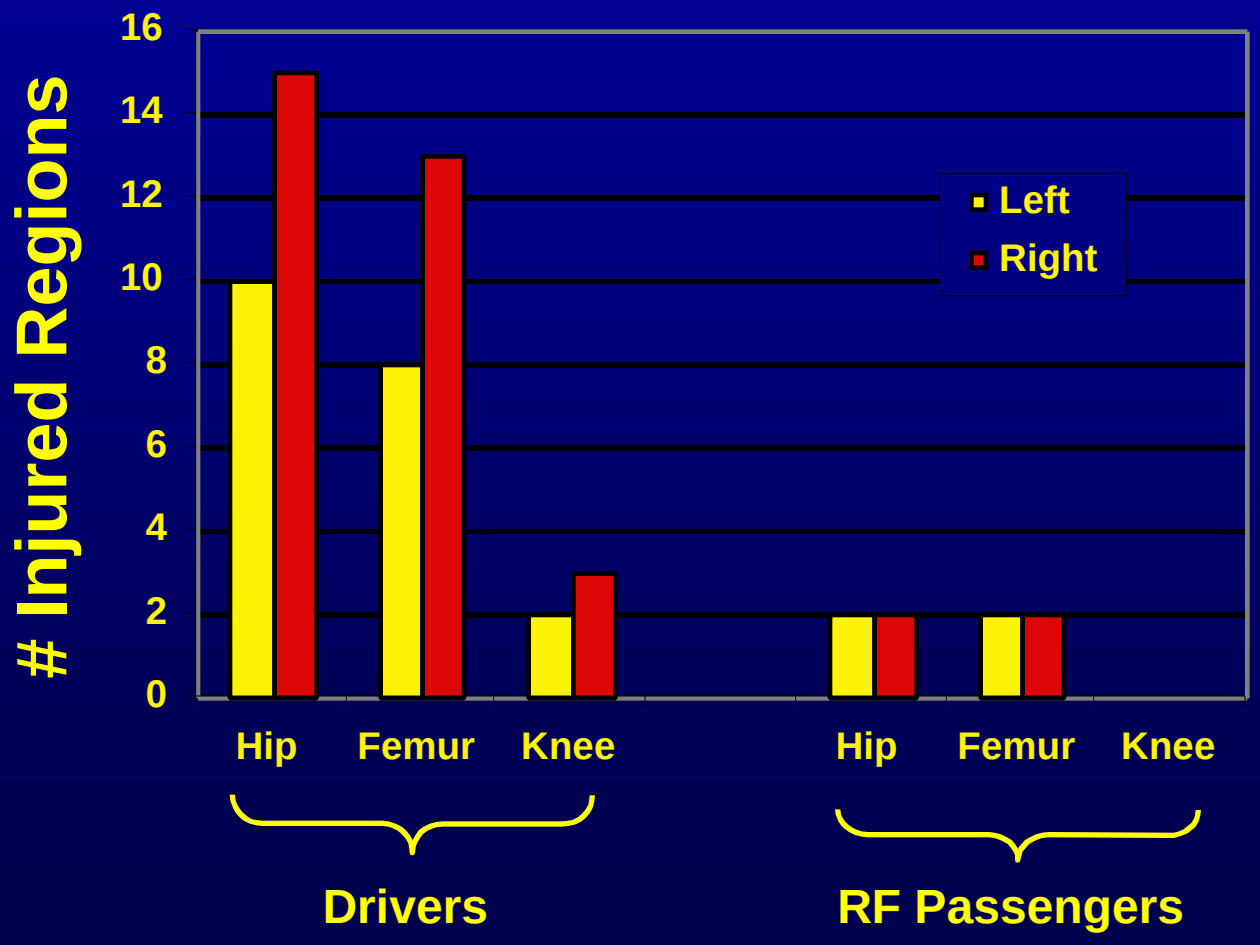
Distribution of Injured Regions by Side of Body



U of M CIREN

K-T-H Fractures/Dislocations in UM CIREN as of 8/31/99

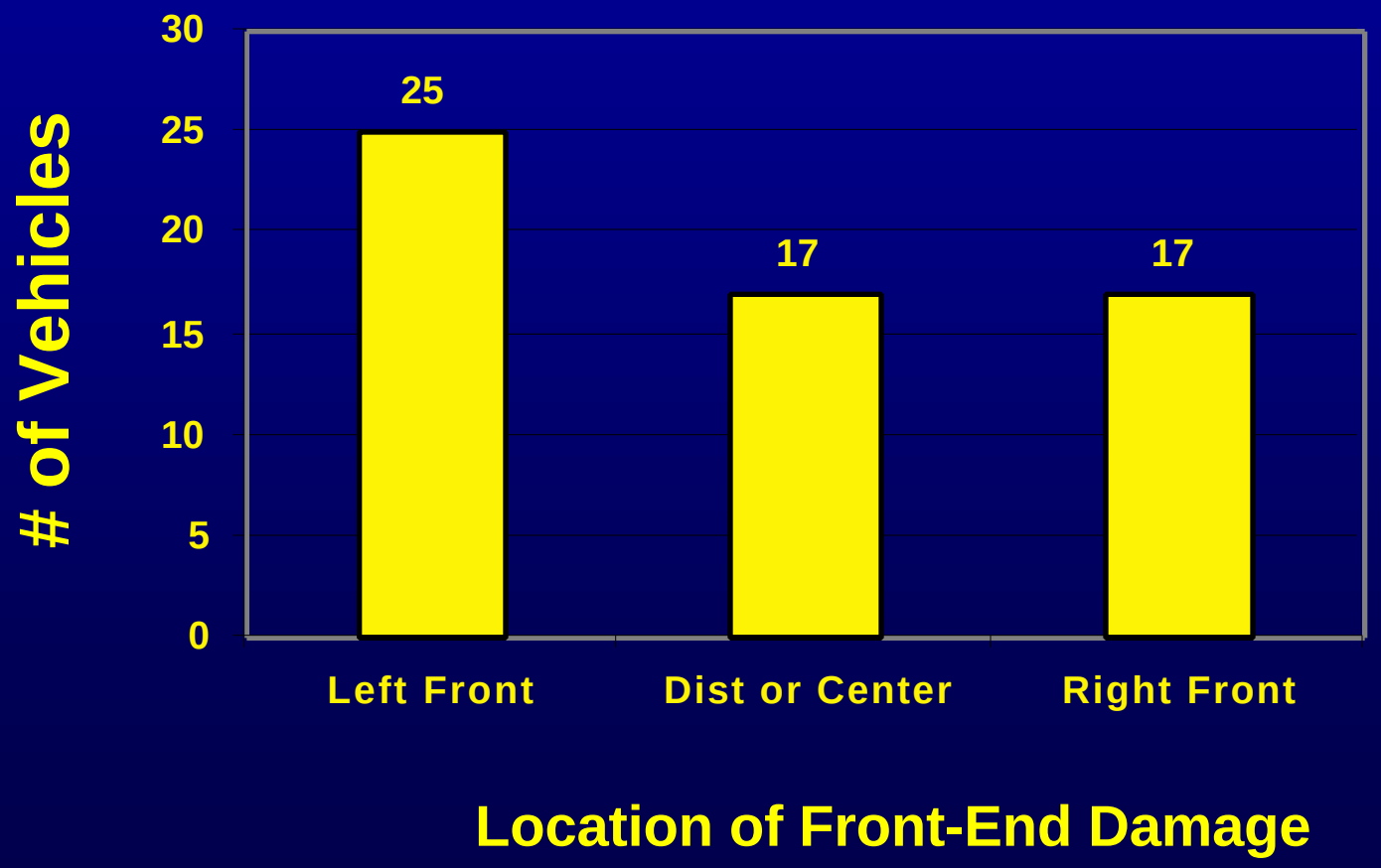
Distribution of Injured Regions by Occupant Location and Side of Body



U of M CIREN

Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

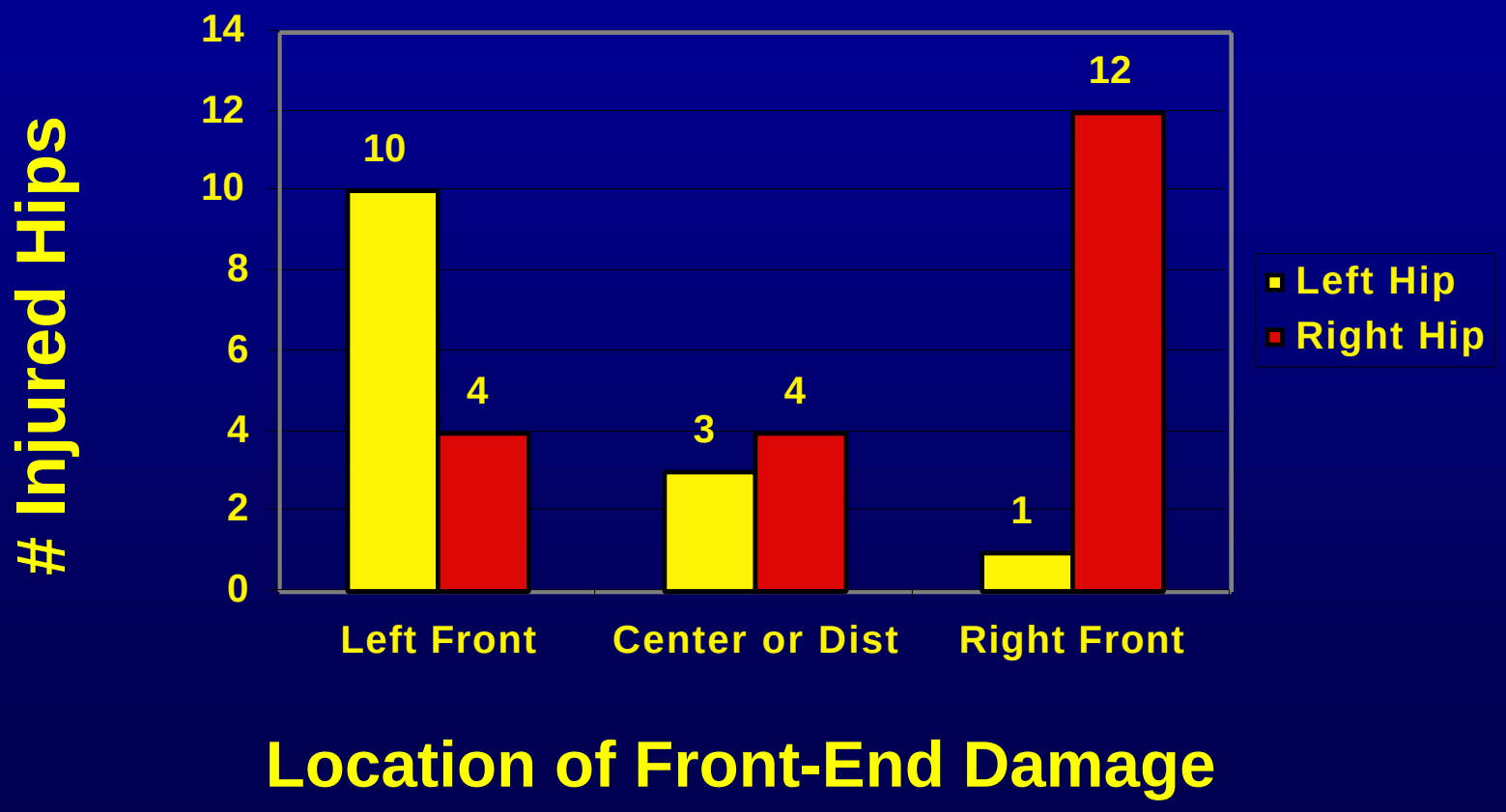
Distribution of Front-End Damage Location for Frontal Crashes Resulting in Femur or Hip Fx/Disloc.



U of M CIREN

Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

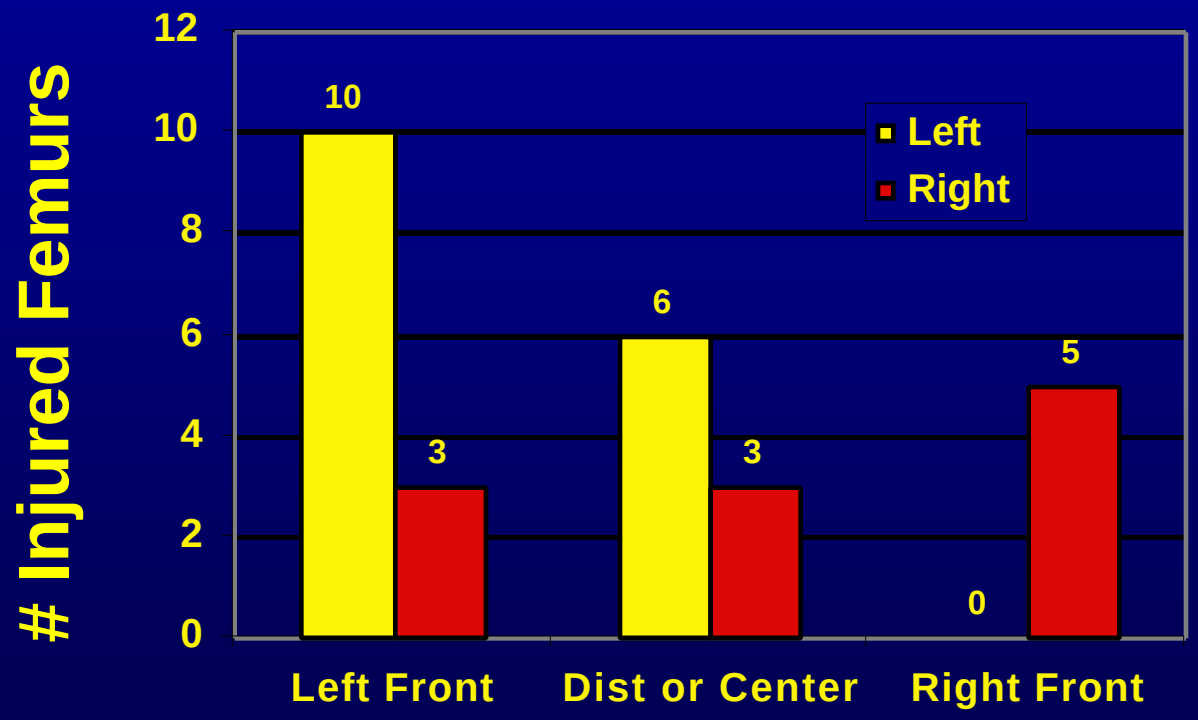
Side of Hip Fracture/Dislocation by Location of Front-End Damage



U of M CIREN

Femur Fractures in UM CIREN Frontal Impacts as of 5/5/00

Side of Femur Fracture by Location of Vehicle Front-End Damage

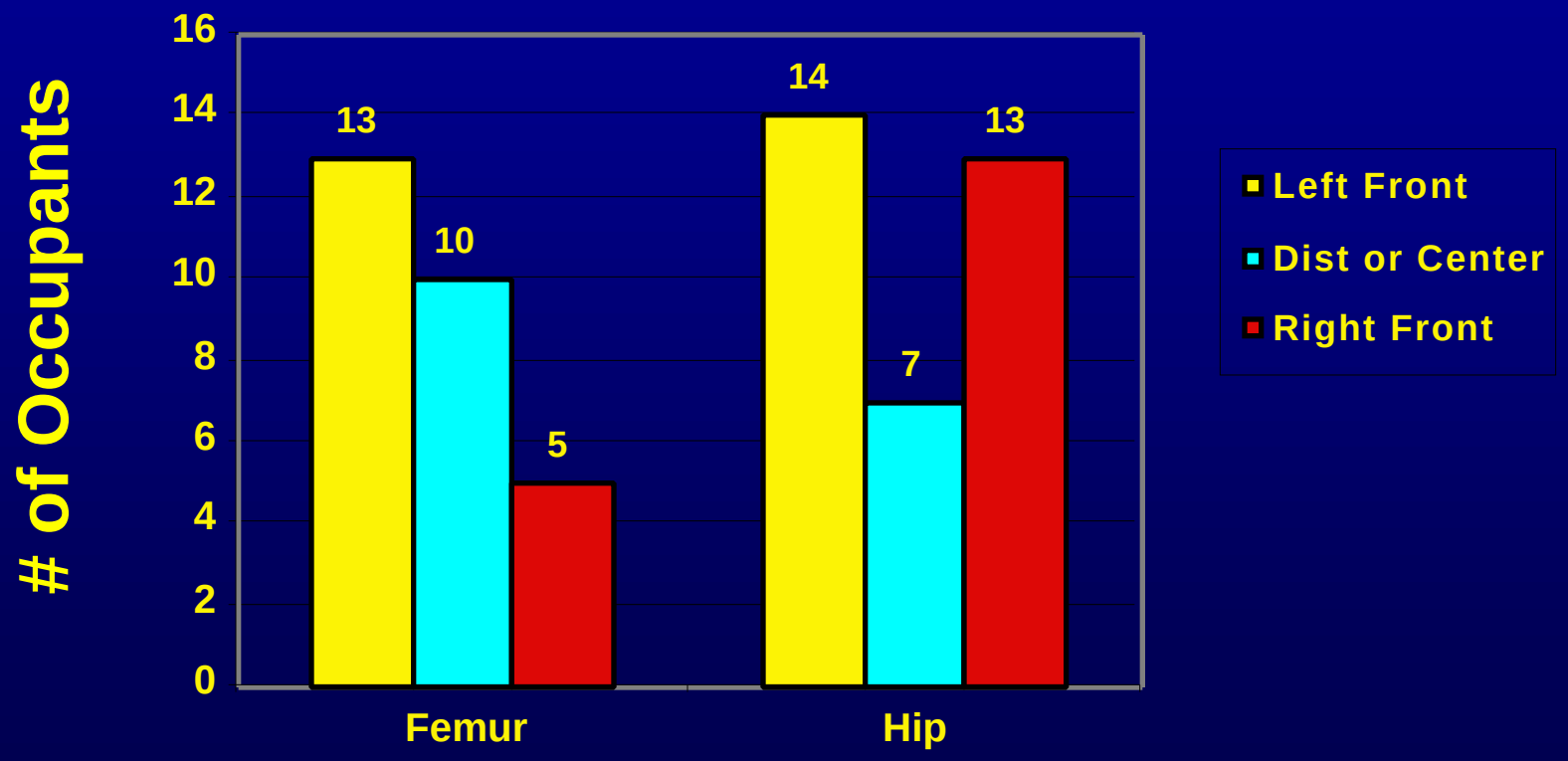


Location of Front-End Damage

U of M CIREN

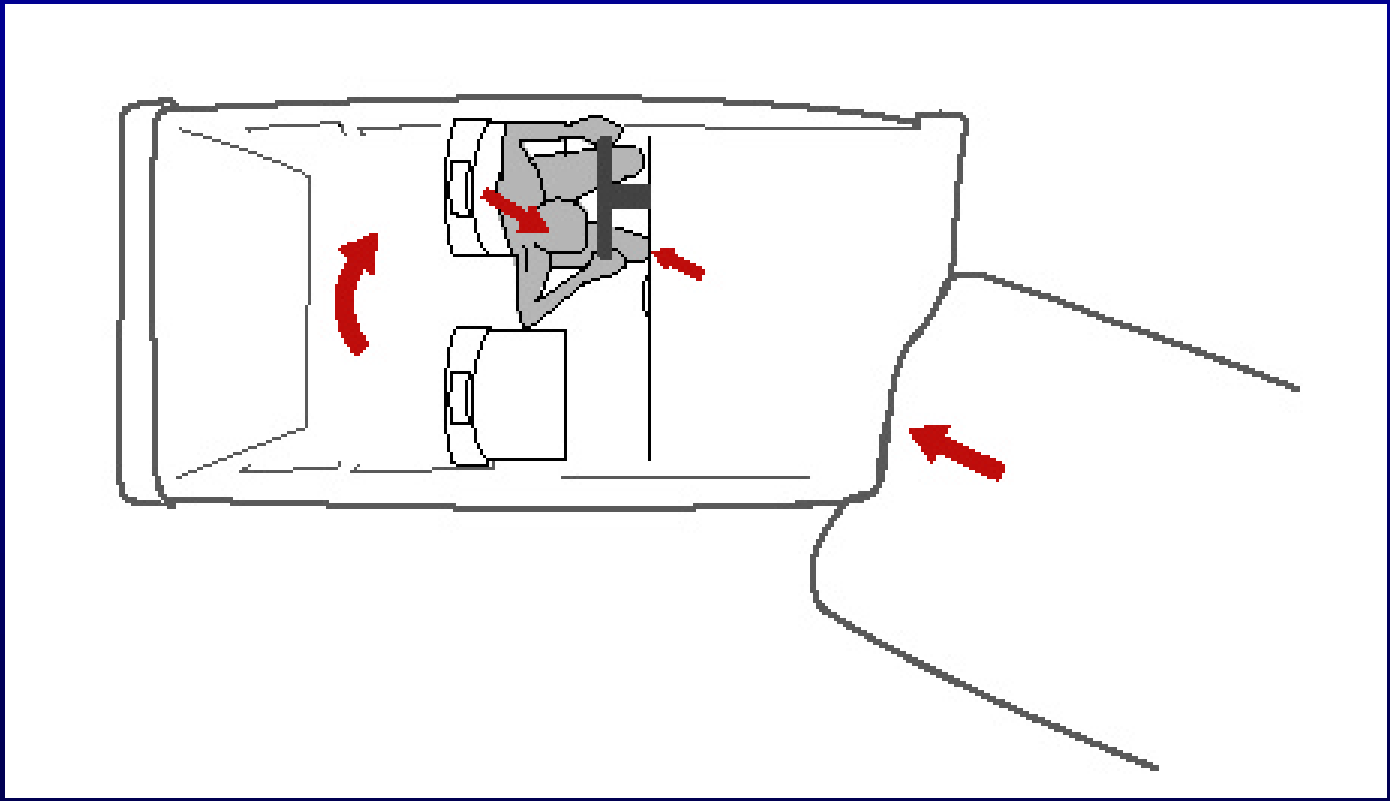
Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

Distribution of Location of Front-End Damage for Hip and Femur Fxs/Dislocations



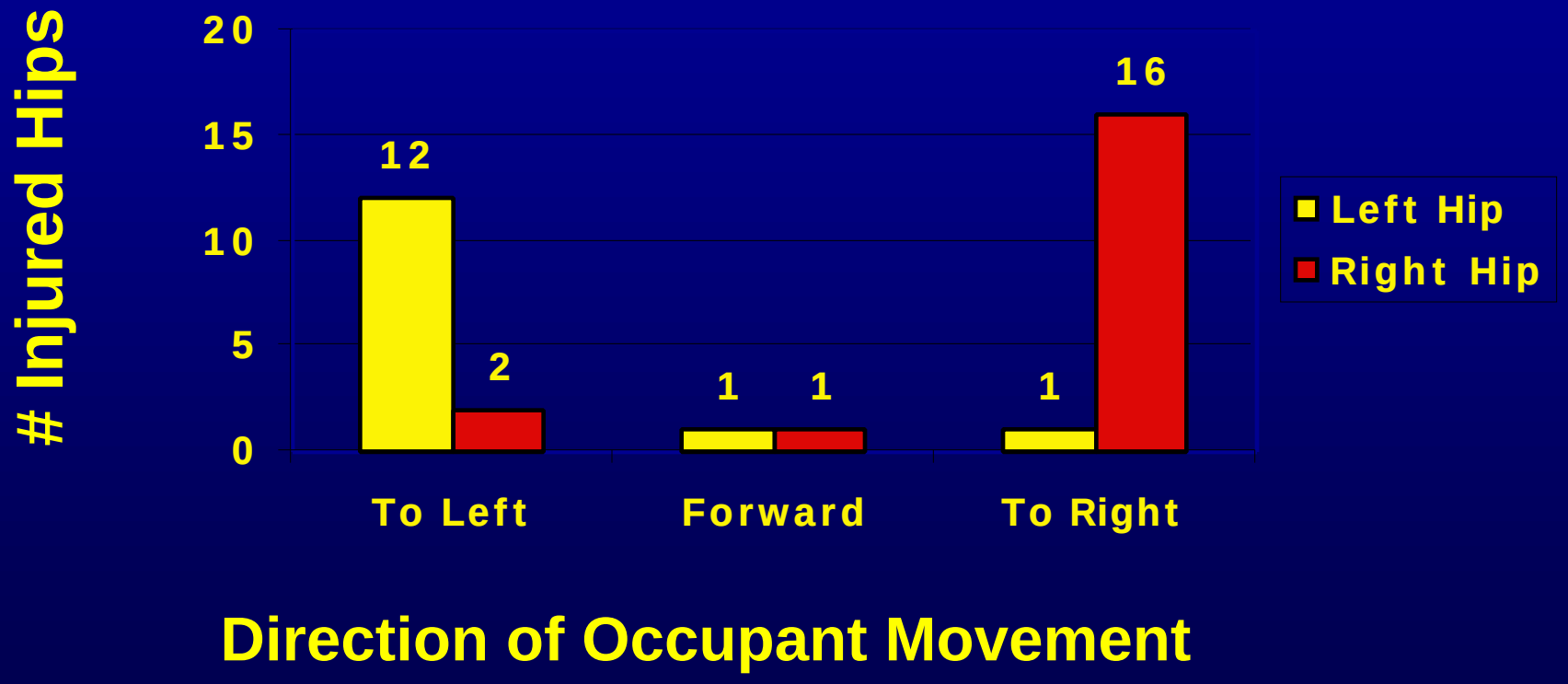
U of M CIREN

Occupant and Vehicle Kinematics in Frontal Impacts



Hip Fractures/Dislocations in UM CIREN Frontal Impacts as of 5/5/00

Side of Hip Fracture by Direction of Occupant Movement

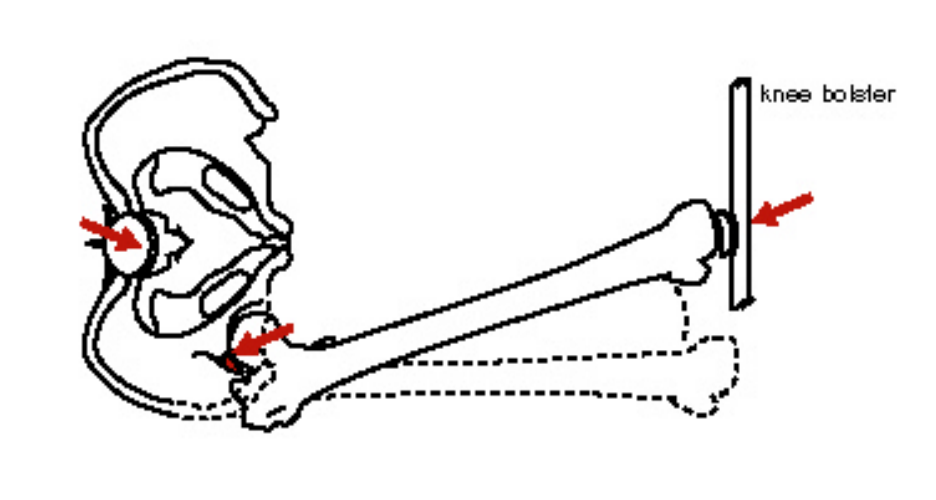


U of M CIREN

Fractures/Dislocations to the Knee-Thigh-Hip Complex

The correspondence of the side of hip fracture to the direction of occupant lateral movement implies two possible contributing factors:

1) hip/thigh adduction



2) asymmetric loading to left and right KTH

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- Many case occupant involved in 25 - 40 mph frontal impacts had only AIS 0 to 1 injuries to the head, face, neck, and chest, but sustained serious and disabling injuries to the lower extremities.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- Many case occupant involved in 25 - 40 mph frontal impacts had only AIS 0 to 1 injuries to the head, face, neck, and chest, but sustained serious and disabling injuries to the lower extremities.
- There are relatively few serious knee injuries compared to thigh and hip injuries.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- Many case occupant involved in 25 - 40 mph frontal impacts had only AIS 0 to 1 injuries to the head, face, neck, and chest, but sustained serious and disabling injuries to the lower extremities.
- There are relatively few serious knee injuries compared to thigh and hip injuries.
- Most hip fractures occurred to the posterior wall/column of the acetabulum, which is consistent with axial loading through the knee and thigh from contact with the knee bolster.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- A large number of femur and hip fracture/dislocations have occurred for crash severities of 25 - 35 mph in the (range of 208 and NCAP testing).

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- A large number of femur and hip fracture/dislocations have occurred for crash severities of 25 - 35 mph in the (range of 208 and NCAP testing).
- No clear relationship between femur and hip fractures and rearward knee bolster intrusion is observed.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- There is a nearly uniform distribution of occupant age from 20 to 70 years for occupants with femur and hip fractures & dislocations, although hip fractures appear to be more likely than femur fractures in the elderly.
- Use of a lap belt restraint has limited influence on reducing femur and hip fractures/dislocations.
- There has been a relative increase in the number of hip fractures compared to femur fractures in 1997 - 1999 model years.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- There is a nearly uniform distribution of occupant age from 20 to 70 years for occupants with femur and hip fractures & dislocations, although hip fractures appear to be more likely than femur fractures in the elderly.
- Use of a lap belt restraint has limited influence on reducing femur and hip fractures/dislocations.
- There has been a relative increase in the number of hip fractures compared to femur fractures in 1997 - 1999 model years.
- Femur and hip fractures/dislocations seem to be biased toward taller and heavier occupants.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

- Hip Fx/Dislocations tend to occur when the conditions of impact induce lateral as well as forward body movement.

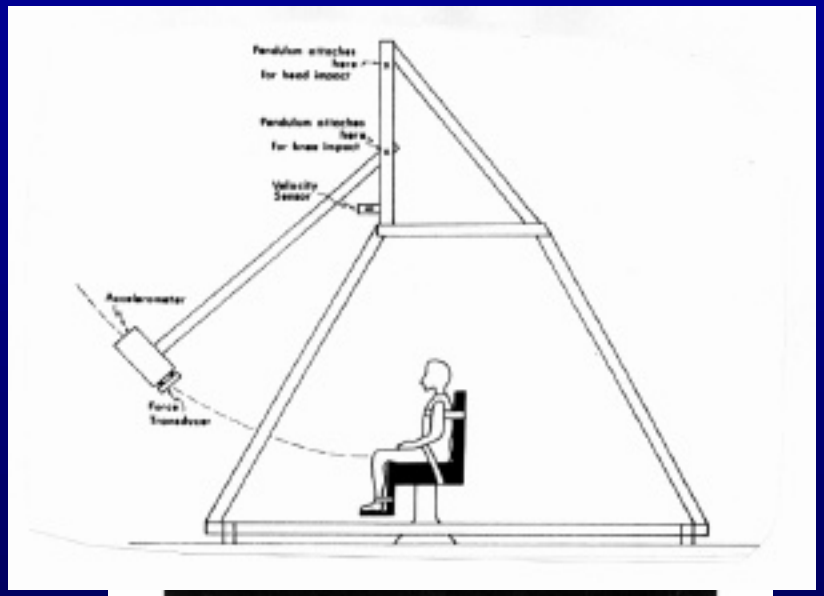
Fractures/Dislocations to the Knee-Thigh-Hip Complex
Summary of Observations from UM CIREN Database

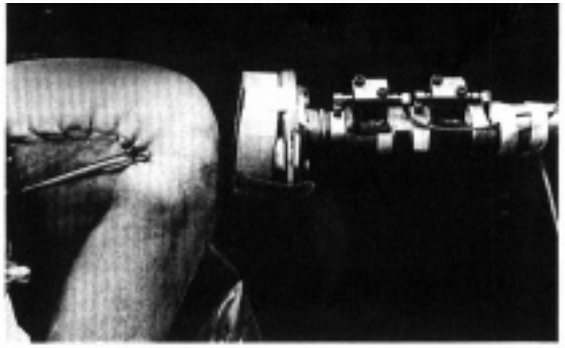
- Hip Fx/Dislocations tend to occur when the conditions of impact induce lateral as well as forward body movement.
- This implies that hip adduction or asymmetric loading of one thigh over the other, or both, are significant contributing factors to the likelihood of hip fracture/dislocations.

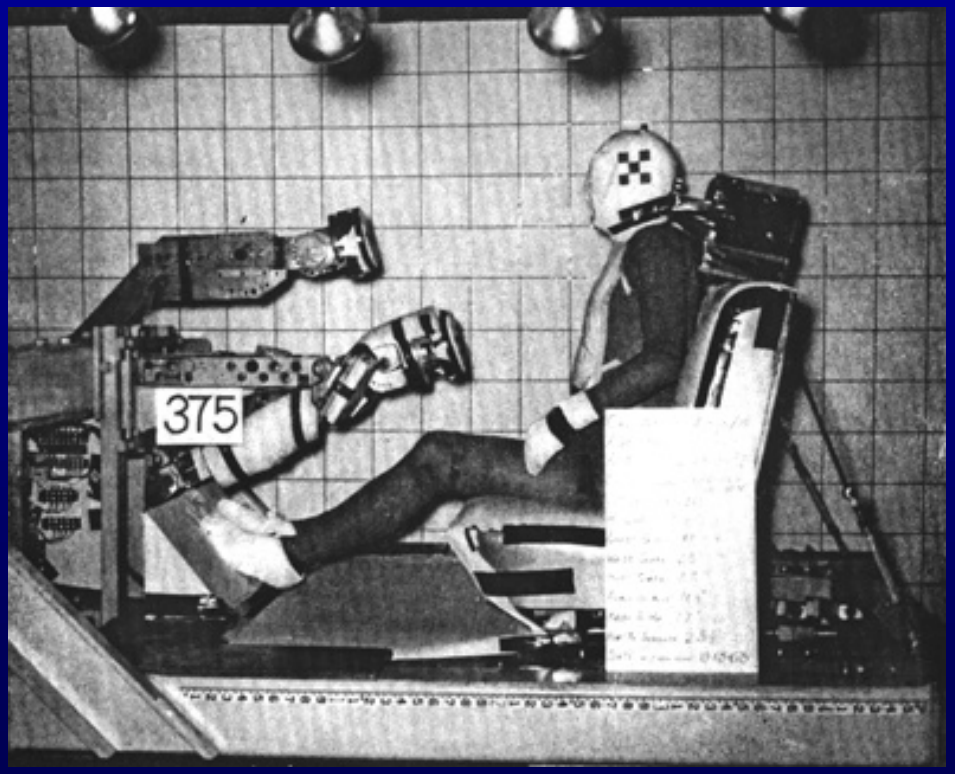
Fractures/Dislocations to the Knee-Thigh-Hip Complex

Biomechanical Studies

Pendulum and Whole Body Testing







U of M CIREN

Fractures/Dislocations to the Knee-Thigh-Hip Complex

Biomechanical Studies

(1965 - 1987)

- L. Patrick et al. 9th Stapp Conference, 1965
- F. Cooke and D. Nagel, 13th Stapp Conference, 1969
- K. Kilfert and G. voight, 15th Stapp Conference, 1972
- J. King et al., 17th Stapp Conference, 1973
- W. Powell et al., 18th& 19th Stapp Conference, 1974 & 1975
- J. Melvin et al., 19th Stapp Conference, 1975
- C. Kroell et al., 20th Stapp Conference, 1976
- D. Viano, 21st Stapp Conference, 1977
- G. Nusholtz et al., 26th Stapp Conference, 1982
- F. Brun-Cassan et al., 7th IRCOBI, 1982
- B. Donnelly and D. Roberts, 31st Stapp Conference, 1987

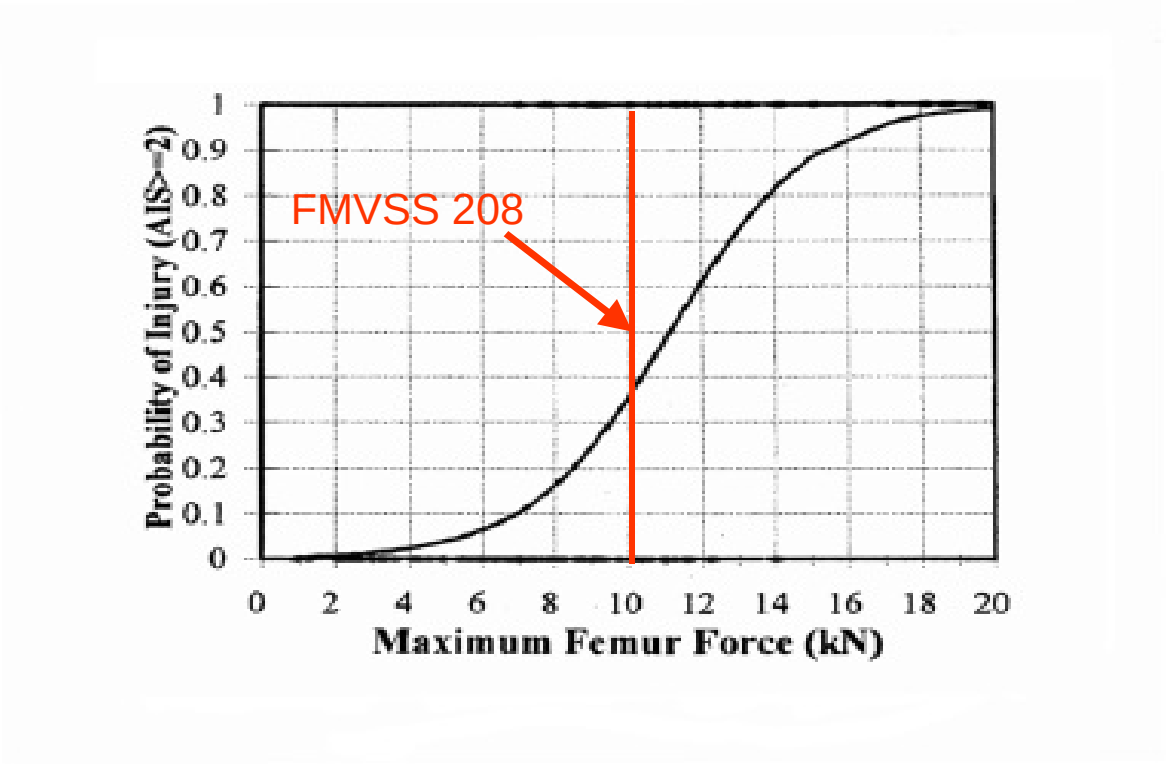
Fractures/Dislocations to the Knee-Thigh-Hip Complex

Biomechanical Studies

- Most studies have dealt with knee and femur fractures.
- Mechanisms of, and tolerance to, hip fractures/dislocations in frontal impact loading are not well understood.
- Causes for femur fracture versus hip-joint fractures and dislocations have not been determined.

Fractures/Dislocations to the Knee-Thigh-Hip Complex
FMVSS 208 K-T-H Injury Criteria vs Injury Risk Curve

- The current FMVSS 208 KTH injury criteria of 10 kN (2250 lb) is based on femur tolerance, not hip tolerance.



Fractures/Dislocations of the Knee-Thigh-Hip Complex

Relevant Questions

- Are the KTH injury criteria of FMVSS 208 appropriate?
- Are energy-absorbing knee bolsters protecting the knees at the expense of the hip or femur?

Fractures/Dislocations of the Knee-Thigh-Hip Complex

Hypothesis

A better understanding of:

1) the factors involved in hip fractures/dislocations versus femur fractures, and
2) hip injury tolerance to frontal impact loading through the knee,

will lead to improved knee bolster, seat, and restraint designs that will reduce the likelihood of hip fractures/dislocations.

Fractures/Dislocations of the Knee-Thigh-Hip Complex

Next Steps

- Examine KTH fracture/dislocation frontal-impact database based on cases from several CIREN centers.
- Study frontal-impact hip fracture/dislocation tolerance and injury factors in the laboratory through a NHTSA Cooperative agreement with U of M.