Pedestrian Knee Ligament Injuries in the U.S.

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Pedestrian Knee Ligament Injuries in the U.S.:

Cruciate ligament injuries without collateral ligament injuries

- **Background:**
  - Knee Ligament Anatomy
  - Ligament Injury Prediction with Pedestrian Legform
  - Motivation for Research Question
  - Relevant Previous Work

- **Methods**

- **Results**

- **Conclusions**
Background: **Collateral Ligaments**
Background: **Cruciate Ligaments**

Injured by shear displacement

Femur

Lateral

Medial

Tibia

Cruciate Ligaments

Anterior
Background: Pedestrian Legforms

FlexPLI

aPLI
Background: Pedestrian legforms

**FlexPLI**

- **EuroNCAP (Current):**
  - Collateral: 19/22 mm
  - Cruciates: 10 mm

**aPLI**

- **EuroNCAP (2023):**
  - Collateral: 27/32 mm
  - Cruciates: None

**Cruciate Ligaments**

**Collateral Ligaments**
Research Question

Do cruciate injuries occur without collateral ligament injuries?

NO?
Ensuring vehicle design prevents collateral ligament injury may be sufficient to prevent cruciate injury

YES?
Protecting collateral ligaments may **not** be sufficient to prevent cruciate injury
Previous Work: Controlled Loading

**Bose et al, J of Biomech Eng (2008)**

PMHS: **Collateral (MCL), Collateral (MCL) + Cruciate (ACL)**

Model: **Cruciate (ACL) failed first with ↑ shear**

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**Bhalla et al, SAE World Congress (2005)**

PMHS: **Collateral (MCL) + Cruciate (ACL)**

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Model:
- Above-knee & proximal tibia: **Cruciate (ACL) fails first**
- PMHS: Proximal tibia:
  - **Collateral (MCL) + Cruciate (ACL)**
- Mid & distal tibia:
  - **Collateral (MCL)**
Previous Work: Controlled Loading

Bose et al, J of Biomech Eng (2008)

PMHS: Lateral loading injured **Collateral** or **Collateral + Cruciate** ligaments

Models: **Cruciates** can fail first in some loading conditions

Depends on impact height and severity

PMHS: **Collateral (MCL) + Cruciate (ACL)**

Model: **Cruciate (ACL)** failed first with ↑ shear

PMHS: **Collateral (MCL), Collateral (MCL) + Cruciate (ACL)**

Above-knee & proximal tibia: **Cruciate (ACL)** fails first

PMHS: Proximal tibia: **Collateral (MCL) + Cruciate (ACL)**

Mid & distal tibia: **Collateral (MCL)**
Previous Work: Full-body PMHS Testing

Kerrigan et al, IRCOBI (2012)

• Analysis of whole-body PMHS vehicle tests:
  • 17 UVa
  • 24 other institutions

• Struck side knee:
  • 9 cruciate + collateral injuries
  • 5 collateral injuries (only)
  • 4 cruciate injuries (only)

Crandall et al., Int J Crashworthiness, 2006
Previous Work: Full-body PMHS Testing

Kerrigan et al, IRCOBI (2012)
- Analysis of whole-body PMHS vehicle tests:
  - 17 UVa
  - 24 other institutions
- Struck side knee:
  - 4 cruciate injuries (only)
  - 5 collateral injuries (only)
  - 9 cruciate + collateral injuries

Full-body PMHS: Collateral and cruciate ligament injuries can occur separately or together.
Previous Work: Epidemiology

Teresiński & Mądro, Forensic Sci Int (2001)

- Autopsies:
  - 357 fatally-injured pedestrians in Poland
  - Most common mechanism: bending in medial or lateral impact

Bending: **Collateral** injury

More Bending: **Collateral + Cruciate** injury
Previous Work: Epidemiology

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Bending: Collateral injury

More Bending: Collateral + Cruciate injury

**Epidemiology:** Isolated cruciate injury in only 7% of injured knees
Isolated Cruciate Ligament Injury in US Pedestrian Crashes

**NTDB** (National Trauma Data Bank)

- How often cruciate injuries occur in absence of collateral injuries

**PCDS** (Pedestrian Crash Data Study)

- Impact conditions associated with isolated cruciate injury
Methods: NTDB

**NTDB (National Trauma Data Bank)**

- 2007-2016: Research Data Set (RDS)
- 2017: Trauma Quality Programs (TQP)
- Trauma Center admissions:
  - Pedestrians
  - Known age
- Knee injuries identified with ICD-9 & ICD-10 diagnostic codes

4,726 pedestrians with knee ligament injury
(No information about vehicle or crash)
Results: NTDB

**Age 0-15**
- Collateral Injuries Only: 116 (44.6%)
- Cruciate Injuries Only: 94 (36.2%)
- Both: 50 (19.2%)

**Age 16+**
- Collateral Injuries Only: 1707 (38.2%)
- Cruciate Injuries Only: 1387 (31.1%)
- Both: 1372 (30.7%)
Results: NTDB

Age 0-15
- Collateral Injuries Only: 116 (44.6%)
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Age 16+
- Collateral Injuries Only: 1707 (38.2%)
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- Both: 1372 (30.7%)

Suggests isolated cruciate injuries not substantially more common among shorter pedestrians or taller pedestrians.
Methods: PCDS

PCDS (Pedestrian Crash Data Study)

- 1994-1998
- Knee ligament injuries identified with AIS-90
  - Cruciate/collateral injuries not differentiated
    - Narrative case documentation searched for injury detail
- Isolated cruciate injury: detailed case review

8 pedestrians with knee ligament injury
1 case with isolated cruciate injury
(Detailed vehicle & crash information)
Results: PCDS case with isolated cruciate injury

1990 Hyundai Sonata

- Impact speed 50 km/h (30 mph)
- No braking
- First contact at left bumper

65 year-old male, 170 cm (5’7”)

- Walking slowly
- Struck on right side, with right leg forward
- Cruciate injury to right knee
Results: PCDS case with isolated cruciate injury

1990 Hyundai Sonata
• Impact speed 50 km/h (30 mph)
• No braking
• First contact at left bumper

65 year-old male, 170 cm (5’7”)
• Walking slowly
• Struck on right side, with right leg forward
• Cruciate injury to right knee
• Knee height 4 cm above top of bumper

Example of isolated cruciate injury in a typical pedestrian impact scenario

Shear displacement at knee
Conclusion #1

Do cruciate injuries occur without collateral ligament injuries?

- NO?
- YES

Cruciate injuries do occur without collateral ligament injury in real-world cases

- NTDB: Almost ⅓ of pedestrian knee ligament cases
- PCDS: Common pedestrian impact scenario

Supports consideration of cruciate injury in assessments of pedestrian knee injury risk
Conclusion #2

Risk of isolated cruciate ligament injury & relative knee/bumper height

- PCDS: Isolated cruciate injury in below-knee impact
- Previous modeling: Isolated cruciate injury in above-knee & below-knee impacts
- NTDB: Similar proportions of children & adults sustained isolated cruciate injuries

Unclear whether legform testing at a single launch height could predict cruciate injury risk for taller or shorter pedestrians
Conclusion #3

• Combined data from 2 sources
  • NTDB \(\rightarrow\) very large number of recent cases (but only medical records)
  • PCDS \(\rightarrow\) crash and injury detail (but on small number of older cases)

Large-scale, comprehensive, representative pedestrian dataset could improve analyses of pedestrian injuries with modern vehicles
Contact Info

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