PCL, ACL, and MCL rupture in rear-seat occupants in offset/frontal automobile collisions

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Introduction
A goal in forensic biomechanics is to determine if an injury mechanism is consistent with the sequence of physical events and to determine if the injury could have been prevented. A case analysis is presented where textbook injury mechanics did not explain the complex knee trauma sustained by a rear seat occupant in an offset/frontal impact. However, vehicle and occupant kinematic analyses and examination of the vehicle interior led to a specific understanding of a unique injury mechanism and prevention.

Methods
An accident reconstruction engineering analysis was performed to determine the collision dynamics. Occupant kinematics were predicted by review of crash tests conducted at similar impact configurations and occupant simulation software. Probable secondary contacts between the occupant and the vehicle interior were hypothesized.
An exemplar size occupant was situated in an exemplar vehicle to determine the physical proximity and specific design characteristics of the probable secondary contact structures.

Results
The principle direction of force applied to the car from -30° (approximately 11 o’clock on a clock diagram), and the nearly instantaneous change in velocity was 24 kph. A 37 year-old male (183cm 95.5kg) seated in the left-rear position (driver’s side) of a 1999 Dodge Intrepid sustained a multi-ligamentous injury to his right knee.
This multi-ligamentous injury consisted of complete rupture of the posterior cruciate ligament (PCL), anterior cruciate ligament (ACL), and medial collateral ligament (MCL) with associated meniscus damage. The left rear and right rear occupants were both unrestrained.

The impact resulted in occupant kinematics forward and to the left relative to the vehicle interior. The inspection of the exemplar vehicle with exemplar occupant showed that in a pre-impact normal seated posture there was a 20cm horizontal distance between the front of the knee and the back of the driver’s seat. Had the rear occupant been restrained, secondary contact between the occupant’s knees and the rear of the driver’s seat would not be expected (Chandler and Christian 1970). Unrestrained however, forward excursion of the occupant to the point of contact occurred in this case. Inspection of the back of the driver’s seat revealed a horizontal support bar 50cm above the floor (Figure 1).

Figure 1. Distance from floor to horizontal support bar.
The blue line indicating the location of the horizontal support bar
The exemplar occupant was moved forward into a simulated knee impact position and the horizontal support bar contacted at and below the tibial tuberosity (figure 2). Above and below the support bar was very compliant material susceptible to deformation.

![Figure 2. Orientation of horizontal support bar and the occupant's lower extremity during a simulated forward excursion](image1)

**Discussion**

As a result of the unrestrained knee impact, the horizontal support bar arrested the forward motion of the tibia while the compliant area above the bar allowed forward displacement of the femur due to the forward inertia of the pelvis, abdomen and torso (Figure 3).

![Figure 3. Seatback horizontal support bar inducing posterior translation of the tibia relative to the femur.](image2)

This differential motion between the femur and tibia resulted in posterior translation of the tibia relative to the femur, which was the mechanism of the PCL trauma. The lateral motion of the occupant was arrested by contact with the left-rear door. Meanwhile, the right rear occupant was forced forward and to the left onto the right lower extremity of the left rear occupant. The applied force onto the flexed right knee resulted in valgus loading with lateral rotation of the tibia, which was the mechanism for ACL/MCL trauma.
Restraint of the right rear occupant would have prevented the valgus loading and resultant ACL/MCL trauma sustained by the left rear occupant. Restraint of the left rear occupant would have prevented the secondary knee contact and resultant PCL trauma. An alternative design of the seat and specifically the geometry and location of the horizontal support bar should also be considered to prevent knee injury to rear seat occupants.

References

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