Knee Bolster Airbag Injury Assessment for Children

Julie Bing, John Bolte IV

Injury Biomechanics Research Laboratory, The Ohio State University

Injury Biomechanics Research Laboratory – The Ohio State University

The Children's Hospital of Philadelphia® RESEARCH INSTITUTE – Center for Child Injury Prevention Studies

INTRODUCTION

- Knee bolster airbags are relatively new safety features which are currently making their debut into some vehicle models. These airbags deploy low on the dashboard and generally strike adults at the mid-tibia, as shown in Figure 1.
- The airbags serve a dual purpose:
  - Absorb forces of impact to prevent lower extremity injury
  - Prevent the occupant from submarining beneath the frontal airbag
- Some safety features that are designed for adults are hazardous to children. For example, frontal airbags have saved countless adult lives but have been blamed for the death of over 100 children [2].
- Although the back seat is the safest place for children [3], 12% children aged 4-7 years are front seat passengers (Figure 2).
- Little research has been done on pediatric lower extremities, due in part to the lack of instrumentation and biofidelity of pediatric ATD extremities. Injuries to this region, while generally not life threatening, can still cause severe impairment and permanent disability [5].

Figure 1: Knee bolster airbag [1]

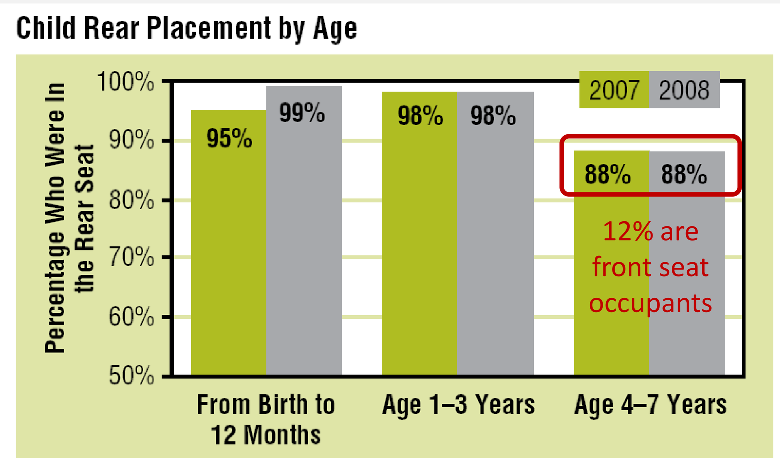

Figure 2: The 4-7 year age group has the highest frequency of front seat occupancy [4].

OBJECTIVES

- Identify real-world risk of pediatric lower extremity injury in frontal crashes
  - Age of affected population, typical seating positions, types of restraint used, mechanisms of injury
- Add instrumentation to a pediatric ATD to capture appropriate data
- Perform airbag deployment tests
  - Simulate many real-world situations
  - Compare data to published pediatric injury reference values [6, 7]

Figure 3: Six-year-old ATD

METHODS

- The standard six-year-old Hybrid III lower extremity is comprised of a fixed pelvis, clevis knee, and clevis ankle.
- Standard instrumentation is a load cell in the femur only.
- For this study, the instrumentation shown in Figure 4 was added to the ATD's lower extremities. 3-aω blocks record linear acceleration and angular rate about all three axes. The foot pressure sensors measure force in the z-direction.
- Static airbag deployments were performed with the ATD in several realistic seating positions.
- Initial tests indicated the need for direct tibia force and moment measurements. The tibia strain gauges were introduced for Tests 007-012. They are capable of measuring force in the z-direction and moments about the x- and y-axes.

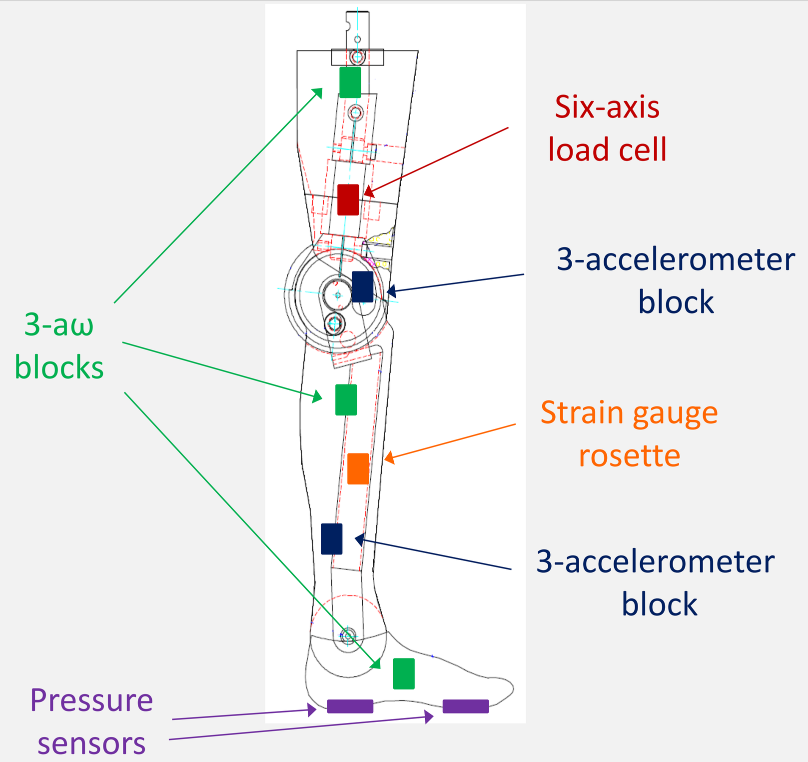

Figure 4: Lower extremity instrumentation

RESULTS & DISCUSSION

Contact Point: Knees

Figure 5: Knee bolster airbag aligned with ATD's knees

For three tests (Tests 004, 008, 012), the ATD's feet were positioned flat on the floor with the knees at a 90° angle (Figure 5). In this position, the airbag made contact with the ATD at the knee. Axial forces were examined in the femur and tibia. The peak axial forces were near the predicted injurious range.

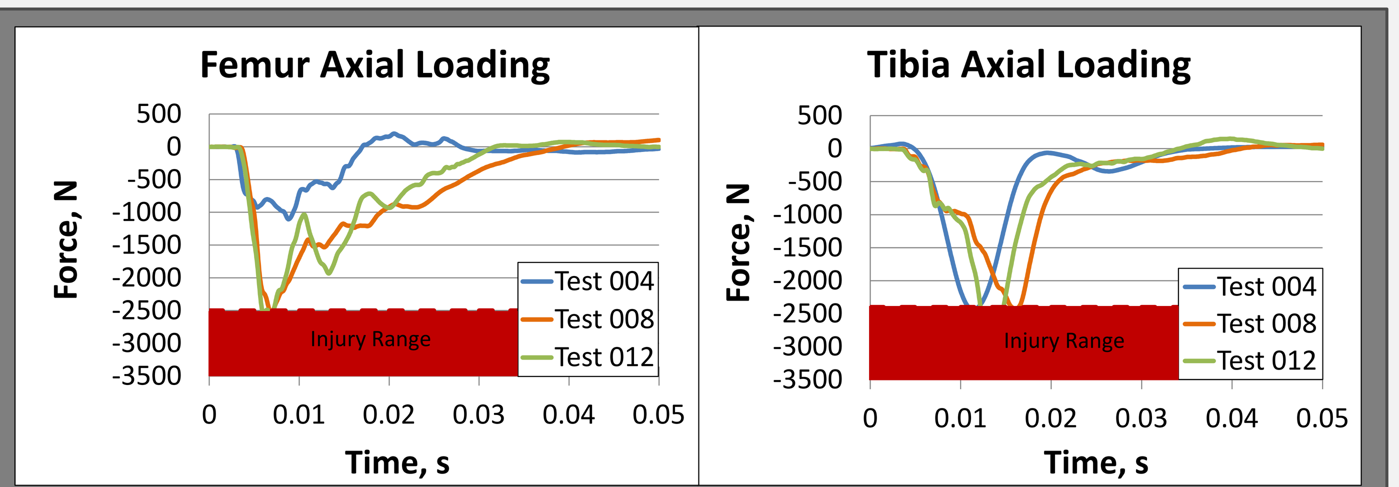

Figure 6: Axial loading in the long bones when the knee bolster airbag contacts the knees. Most values peaked near the injury threshold as reported by Ivarsson [6] and Mertz [7]. Note that Test 004 involved a differently designed knee bolster airbag than Tests 008 or 012.

Contact Point: Feet

Figure 7: Knee bolster airbag aligned with ATD's toes

Several tests were executed such that the airbag made contact with the ATD's feet (either the toes, soles, or heels). This often resulted in high foot rotation rates >1500 degrees/second. The foot reached the end of its range of motion and hit the hard stop in the ankle joint abruptly. Spikes in the tibia force and moment measurements occurred.

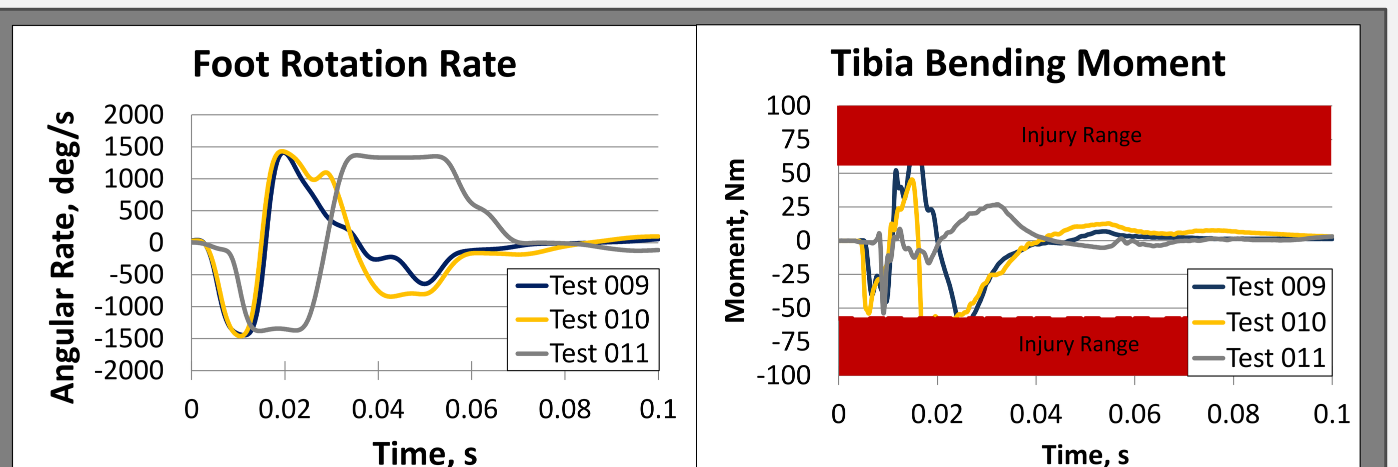

Figure 8: High foot rotation rates occurred when the airbag contacted the feet (either the toes, soles, or heels). The rates exceeded the range of the sensors in Test 011. No quantitative injury criteria exists for this parameter. High tibia moments were observed when the foot hit the hard rotation stop in the ankle joint.

			Series I Femur load cell, Tibia values calculated					Series II Femur load cell, Tibia strain gauges					
			Test 002	Test 003	Test 004	Test 005	Test 006	Test 007	Test 008	Test 009	Test 010	Test 011	Test 012
Parameter	Injury Threshold	Units	Booster Seat	Feet on floor	Feet on floor	Toes on dash	Heels on dash	Booster Seat	Feet on floor	Toes on dash	Heels on dash	Heels on dash	Feet on floor
Femur Forces	2500	N	1150	300	1200	320	350	800	2500	700	700	1300	2600
Femur Moments	73.3	Nm	45	17	57	14	19	25	42	41	52	35	68
Tibia Forces	2400	N	--	420	2500	470	560	1800	2200	800	1100	1800	3000
Tibia Moments	57.6	Nm	--	--	--	--	--	73	40	78	80	55	37
Tibia Index	1.1	None	--	--	--	--	--	1.1	0.75	0.9	0.95	1.1	1.1

Key	
(green)	= Below injury threshold (safe)
(yellow)	= Approaching injury threshold
(red)	= Past injury threshold (unsafe)

Table 1: Summary of the main injury parameters examined in each trial. Note that the tibia data was limited for Series I. Tibia strain gauges were added for Series II.

The tibia index (TI) is commonly used to predict tibia injury based on a combination of axial force and bending moment [8].

$$TI = \frac{F_Z}{F_{CR}} + \frac{M_Y}{M_{CR}}$$

F_{CR} and M_{CR} are critical force and moment values which have been scaled to age-appropriate values [6]: F_{CR} = 4.78 kN and M_{CR} = 74.2 Nm. A tibia index value in excess of 1.1 indicates the potential for injury.

CONCLUSIONS

- Knee bolster airbags may pose a risk to pediatric lower extremities, especially when the main loads are applied along the axis of the long bones.
- Direct methods of tibia force and moment measurement are necessary to evaluate injury potential.
- Development of a more biofidelic ankle is necessary to better understand the propagation of the impact from the foot, through the ankle, and into the rest of the extremity.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the National Science Foundation (NSF) Center for Child Injury Prevention Studies at the Children's Hospital of Philadelphia (CHOP) for sponsoring this study and its Industry Advisory Board (IAB) members for their support, valuable input and advice. The views presented are those of the authors and not necessarily the views of CHOP, the NSF, or the IAB members. Also, special thanks to Doug Longhitano and Darrin Rankin from Honda R&D Americas, Inc., the members of the OSU IBRL, and all others who have contributed to this project.

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