Investigation of the Pediatric Shoulder's Resistance to Lateral Impact Loading

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INTRODUCTION

➢ Motor vehicle collisions (MVC), especially those of side impact, are a leading cause of injuries and death among children.[1]

➢ During side impact MVCs, the positions of the occupant's head, neck, and thorax heavily depend on the biomechanical response of the shoulder.[2]

➢ Therefore, having a more biofidelic shoulder in pediatric anthropomorphic testing devices (ATD) is essential to accurately simulate the occupant's response to side-impact MVCs and design better safety measures.

➢ The objectives of this study are: 1)) determine the pediatric shoulder's resistance to medial and posteromedial loading conditions and 2) compare shoulder resistance by age groups.

MATERIALS & METHODS

➢ Previous testing protocol was modified and applied, using VICON optical motion capture, electromyography (EMG), and resistive loading.[3]

➢ A total of 39 pediatric volunteers between 4-18 years old (Table 1) were tested. This age range was selected to represent the 6 year old, 10 year old, and 5th percentile female ATDs.

	Male	Female	Total
4-7 years old	8	7	15
8-12 years old	9	8	17
13-18 years old	2	5	7

Table 1. Volunteer Statistics

➢ A custom linear force applicator (Figure 1) was utilized to displace the shoulder and measure the applied forces. The applicator's design enabled translational motions in all directions to ensure proper alignment and to allow loads to be applied in both medial and posteromedial directions.

➢ The subjects were seated against a support wall, equipped with load cells, in order to limit rotation and translation of the subject and to determine the amount of load translated through the subject's upper torso.

➢ An 8-camera 100 Hz VICON motion analysis system was used to measure shoulder and thoracic displacement. Reflective markers were taped to the skin over the subject's acromion process of both scapulas, manubrium of the sternum, and lateral epicondyle of the right humerus (Figure 2).

➢ For each volunteer, the loading apparatus was placed to the subject's right and the load arm was manually applied (Figure 3). A total of 16 tests were performed per subject: 5 with the subject's muscles relaxed, followed by 3 while tensed, for both medial and posteromedial loading directions.

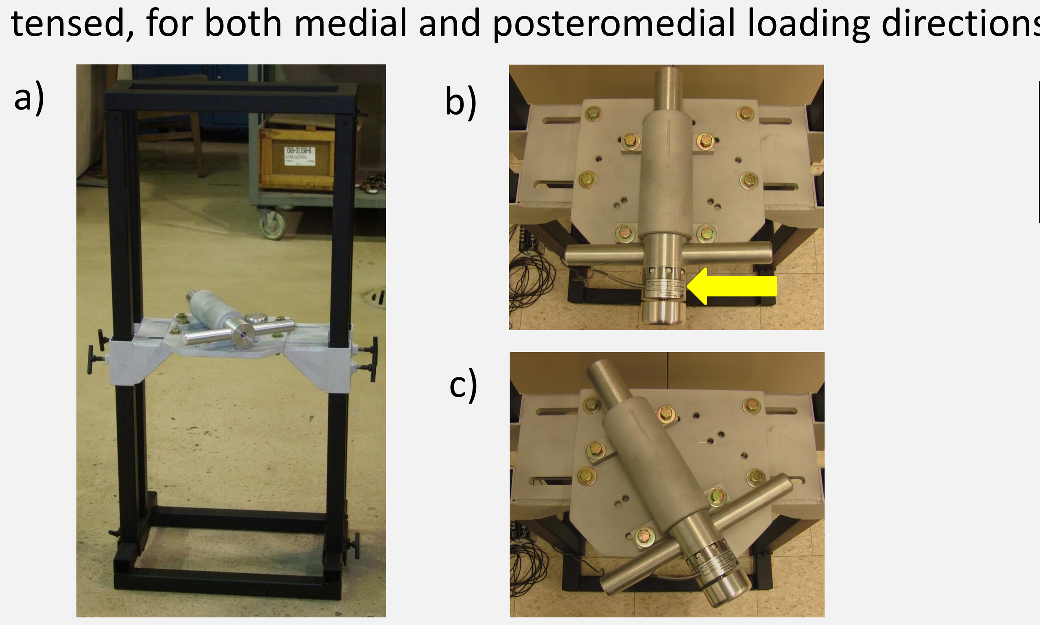

Figure 1. (a) Frame with force applicator; (b) Load cell (arrow) attached to the force applicator shown in a medial loading direction; (c) Force applicator positioned in a posteromedial loading direction.

Figure 2. Placement of the reflexive markers and surface electrodes

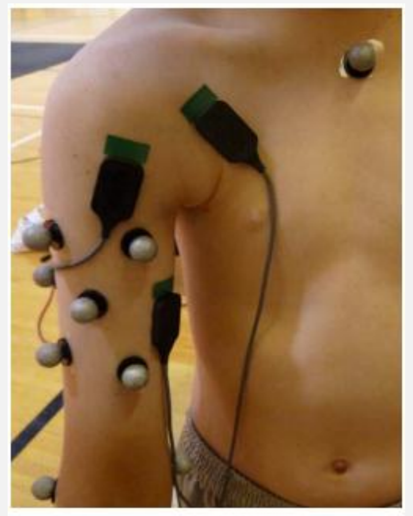

Figure 3. Final set-up with the contralateral load-cell wall

RESULTS & DISCUSSION

➢ Medial testing resulted with minimal shoulder displacement at these low loads due to the clavicle acting as a strut and supporting the shoulder girdle. Due to the limited displacements, medial stiffness was not be calculated for the age groups.

➢ Non-normalized, posteromedial force-displacement data from all trials for each volunteer were averaged to calculate a mean stiffness curve for each subject (Figure 4). The mean curves from all volunteers in an age group were then averaged to calculate a mean curve and standard deviation for each age group. This process was completed for both relaxed and tensed loading conditions (Figure 4).

➢ Shoulder stiffness, k, was then calculated by taking the slope of each age group's mean curve in order to compare shoulder resistance to loading across all age groups and loading conditions (Table 2).

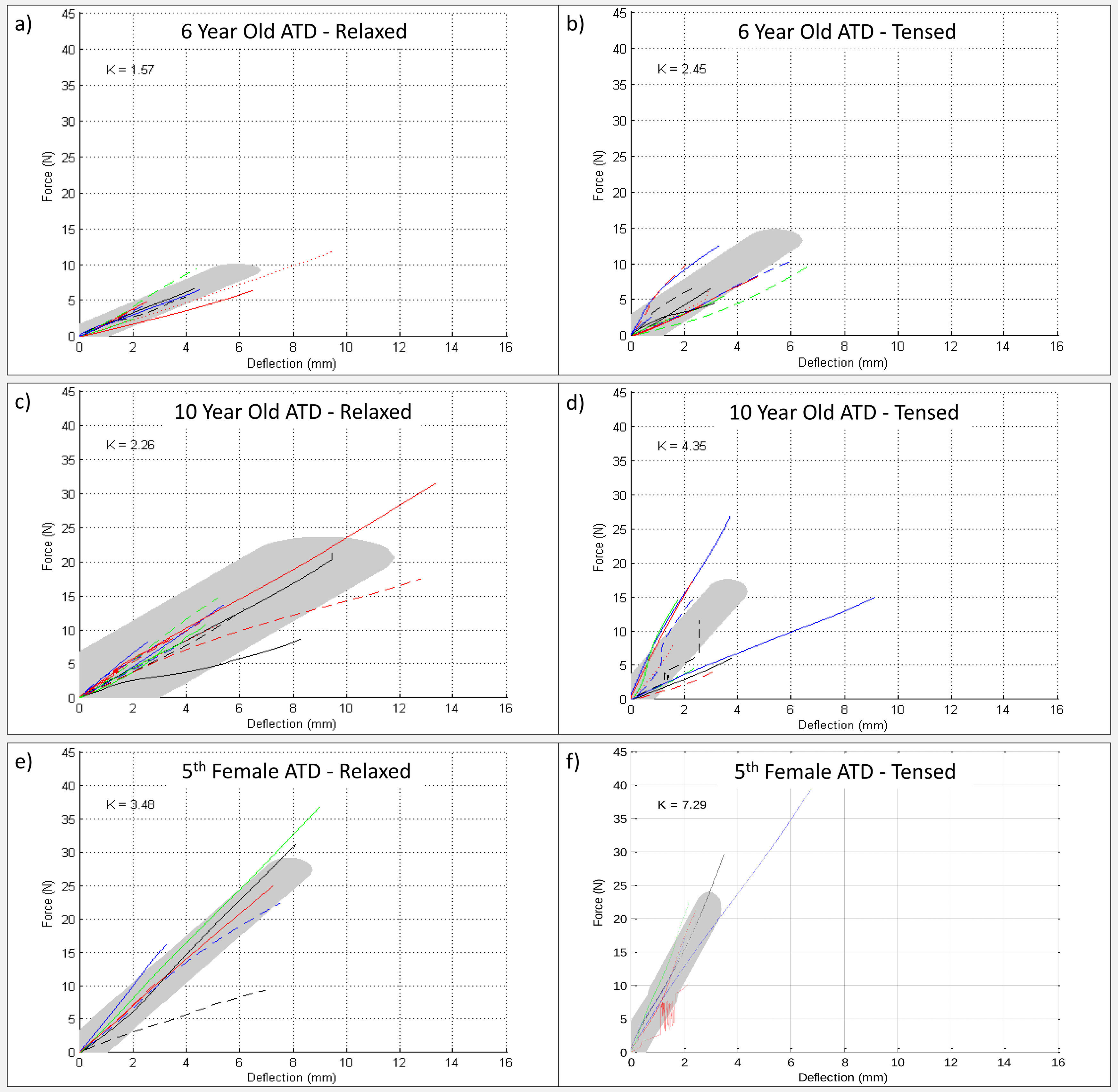

Figure 4. Force-Deflection plots for the posteromedial loading condition:
(a) 6 year old ATD group in the relaxed condition
(b) 6 year old ATD group in the tensed condition
(c) 10 year old ATD group in the relaxed condition
(d) 10 year old ATD group in the tensed condition
(e) 5th Female ATD group in the relaxed condition
(f) 5th Female ATD group in the tensed condition

	Stiffness (N/mm)	
	Relaxed	Tensed
4 -7 years old	1.57	2.45
8 – 12 years old	2.26	4.35
13 – 18 years old	3.48	7.29

Table 2. Posteromedial Stiffness Values

➢ Bone maturation is likely one contributor to the increase in stiffness with age. The older the children are, the more ossified their bones become and thus more stiff.

➢ In children, especially under the age of 12, their bones are still largely cartilaginous, which may translate into greater compliance and lower stiffness of the shoulder.

➢ Soft tissue must also be considered as a contributor to the difference in stiffness. The amount of subcutaneous tissue and muscle present in shoulder region of the volunteers varied by age group.

CONCLUSIONS

➢ Medial stiffness could not be calculated due to limited measured displacement.

➢ Shoulder stiffness increases with age and also with muscle tension for the posteromedial loading direction.

➢ Posteromedial shoulder stiffness should be taken into consideration when designing new pediatric ATDs, to ensure a biofidelic response.

References

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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. The Ohio State University College of Medicine; IBRL: Yun Kang, Tony Vergis; SBL: Dr. Ajit Chaudhari, Steven Jamison ; NHTSA/VRTC: Kevin Moorhouse