MECHANICAL PROPERTIES OF THE SHOULDER LIGAMENTS UNDER QUASI-STATIC AND DYNAMIC LOADING

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INTRODUCTION

The tensile properties of the shoulder ligaments under dynamic loading have not been investigated. A recent finite element model showed the ligaments in the shoulder were subjected to dynamic tensile loading during 8.65 m/s lateral shoulder impact [1]. The mechanical properties of shoulder joints under dynamic loading are needed to better understand shoulder injury mechanisms, to improve shoulder finite element models and to further develop the shoulder of car crash dummies.

METHODS

Thirty-three fresh human shoulders were harvested and bone-ligament-bone specimens of acromioclavicular joint (AC), coracoclavicular ligament (CC) and sternoclavicular joint (SC) were obtained. The age range of test subjects was 47 to 95 years, with 13 shoulders from males and 10 from females. A test fixture and clamps specifically designed for this ligament study and a high-speed Instron machine were used (Fig 1). One quasi-static rate (0.1 %/sec) and two high rates (nominally, 15,000 %/sec and 40,000 %/sec) were used in this study.

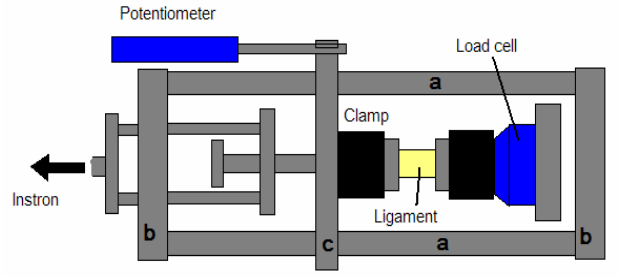

Figure 1. Diagram of the shoulder ligament test setup. Thompson shafts (a) and aluminum plates at the ends (b). The fixture included an additional aluminum plate (c) which was connected and moved with the Instron actuator.

RESULTS AND DISCUSSION

Eighty-three specimens were tested at three different strain rates. In acromioclavicular joint (AC) tests, ligament failure was the most common failure mode. In coracoclavicular (CC) bone-ligament-bone tests, the majority of specimens failed at the ligament. In sternoclavicular joint (SC) tests, the specimen failed at the bone in most cases. In AC and CC tests, 15,000 %/sec tests and quasi-static tests had more bone fracture cases than 40,000/sec tests. The Young's modulus and ultimate load of the three joints were found to be significantly lower in the 0.1 %/sec tests compared to the 15,000 %/sec tests but not significantly different between 15,000 %/sec and 40,000 %/sec tests (Table 1). There was no significant relationship between the ligament cross sectional area and subject age, height and weight. In addition, there was no significant relationship between mechanical properties of the shoulder joints and anthropometric data or age. However, specimens from younger subjects were not available for this study. This appears to be the first published study describing the mechanical and structural properties of the AC and SC. The 40,000 %/sec strain rate is the highest published strain rate ever used and analyzed for ligament studies. Overall, the shoulder ligaments showed larger ultimate strain and smaller ultimate stress and Young's modulus than animal or human knee ligament [2]. The capacity of large ultimate strain in shoulder ligaments may contribute to the large range of motion attainable in the shoulder.

REFERENCES

1. Iwamoto et al. 44th Stapp Car Crash Journal, SAE Paper No. 2000-01-SC19, 2000.
2. Koh et al. 48th Stapp Car Crash Journal, SAE Paper No. 2004-22-0006, 2004.

ACKNOWLEDGEMENTS

This research is supported by a URP grant from Ford Motor Company.

Table 1. Mechanical and structural mean values (+/- standard deviation) of 83 shoulder joints at three different strain rates

	Strain rate (%/sec)	Deflection at failure (mm)	Load at failure (N)	Strain at failure (%)	Young's modulus (MPa)
Acromioclavicular ligament (N=32)	40000 (N=13)	15 (+/- 4.0)	696 (+/- 218.3)	105 (+/- 20)	10.6 (+/- 1.7)
	15000 (N=10)	13 (+/- 7.1)	849 (+/-297.1)	81 (+/- 35)	9.6 (+/- 4.5)
	0.1 (N=9)	11 (+/- 2.1)	464 (+/- 101.1)	80 (+/- 17)	6.3 (+/- 1.2)
Coracoclavicular ligament (N=31)	40000 (N=12)	17 (+/- 7.6)	389 (+/- 194.1)	86 (+/- 34)	10.0 (+/- 3.8)
	15000 (N=10)	14 (+/- 4.3)	345 (+/- 132.1)	58 (+/- 18)	9.0 (+/- 3.8)
	0.1 (N=9)	14 (+/- 4.0)	155 (+/- 80.2)	79 (+/- 39)	3.4 (+/- 1.8)
Sternoclavicular ligament (N=20)	40000 (N=5)	12 (+/- 3.5)	670 (+/- 406.9)	62 (+/- 19)	10.2 (+/- 2.8)
	15000 (N=7)	13 (+/- 3.6)	604 (+/- 255.0)	50 (+/- 13)	12.7 (+/- 2.3)
	0.1 (N=8)	8 (+/- 2.4)	334 (+/- 143.7)	39 (+/- 10)	6.2 (+/- 0.6)