# A NEW THOR SHOULDER DESIGN: ITS RANGE-OF-MOTION IN COMPARISON WITH VOLUNTEERS, THE HYBRID III AND THOR NT

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## ABSTRACT

There is a need for dummies that mimic crash victims' kinematics in oblique and offset frontal collisions. Improved seatbelt-to-dummy interaction in crash testing is also desirable. Hence, a new THOR shoulder was developed and evaluated in comparison with volunteers', the Hybrid III and THOR NT shoulder range-of-motion. The new shoulder has human-like bony landmarks, clavicle curvature and length, and joints. The evaluation showed that the range-of-motion for the static loading of the new shoulder was similar to that of the volunteers. This was not so for the Hybrid III and THOR NT. The data indicates that the new shoulder design can provide more human-like shoulder motions in a crash test.

**Keywords:** Shoulder, Range-of-motion, Biofidelity, Volunteers, THOR

UNTIL RECENTLY, THE SHOULDER COMPLEX has received low priority in the development of frontal impact crash test dummies. The shoulders are rarely exposed to injuries in life-threatening frontal and oblique frontal collisions (Frampton et al. 1997). However, there are several factors that indicate a need for further study of the shoulder complex. One of these is the significant differences in shoulder range-of-motion between humans, the Hybrid III and the THOR Alpha, as shown by Törnvall et al. (2005). Therefore, this study aims to develop a new 50$^{th}$ percentile THOR shoulder design and to compare its shoulder range-of-motion, when mounted on a THOR NT dummy, with that of volunteers, the Hybrid III and THOR NT. The new shoulder design is denoted SD-1; when mounted on the THOR NT it is THOR SD-1 (THOR Shoulder Design, version 1).

## EXPERIMENTAL PROCEDURE

DEVELOPMENT OF A NEW THOR SHOULDER: The new SD-1 was designed to have bony landmarks and a range-of-motion similar to that of a human, to enable improved shoulder belt interaction and kinematics during a collision. The SD-1 was also designed to be easily retrofitted into the upper thoracic spine weldment (spine) of a THOR NT dummy. The THOR NT was chosen as the dummy on which to mount the SD-1 because it was the only one available when the development of the SD-1 was started. The anthropometry of the new shoulder design was generated from a shell model of the seated UMTRI 50$^{th}$ percentile male (UMTRI, 1983), with coordinates for joints and bony landmarks. The bony landmarks of the human scapula were made in the SD-1 in two parts, one representing the superior part of the scapula and the other representing the coracoid process and the acromion (Figure 1). The original dummy gleno-humeral joint was replaced by a rotating cardan joint to decrease size, and thereby minimize the risk of the belt being caught by the joint, and to increase the degree of freedom of the upper arm (Figure 1). The latter facilitates a more human-like motion pattern. To accommodate this change, the upper arm (humerus) was also redesigned.

All of the rotational joints in the SD-1 were provided with sliding bearings to reduce friction. The rotational freedom of the scapula Link I was limited to 120° by a posterior and an anterior rotation stop. The stops were made of Silicon, NEUKASIL RTV 102, with an approximate stiffness of 21 Shore A (Figure 1). The 120° rotational freedom of the scapula Link I was also designed to have a linear resistance which was devised with an open coil spring built into the SD-1 structure. The coil spring was designed to have a torque of 1.67 N/degree when the shoulder is rotated in the anterior direction. The introduction of a coil spring provides the SD-1 with a human-like stiffness of the gleno-humeral joint in the anterior direction. Scapula Link II was confined to a plane upward motion since it may rotate only in the vertical plane relative to the scapula Link I. Its upward rotation is limited by polyurethane covered stops at 90° (Figure 1). The rotation stops of the scapula Link II were made of metal and covered with 2 mm thick polyurethane to reduce contact induced vibration in the SD-1. The rotational joint between scapula Links I and II was angled in such a way that it provides rotation of Link II in the sagital plane when Link I is in forward-most position (Figure 1). The clavicle was provided with cardan joints at its ends to allow for rotation of the clavicle relative to the sternum and to the distal part of Link II. Moreover, a sliding bearing at the sternum end was attached to allow for rotation around the longitudinal axis of the clavicles, as in humans. The upper sternum plate was redesigned to fit the new clavicles; the sternum end of the clavicles was shifted laterally by approximately 30 mm in order to provide a more human-like position.

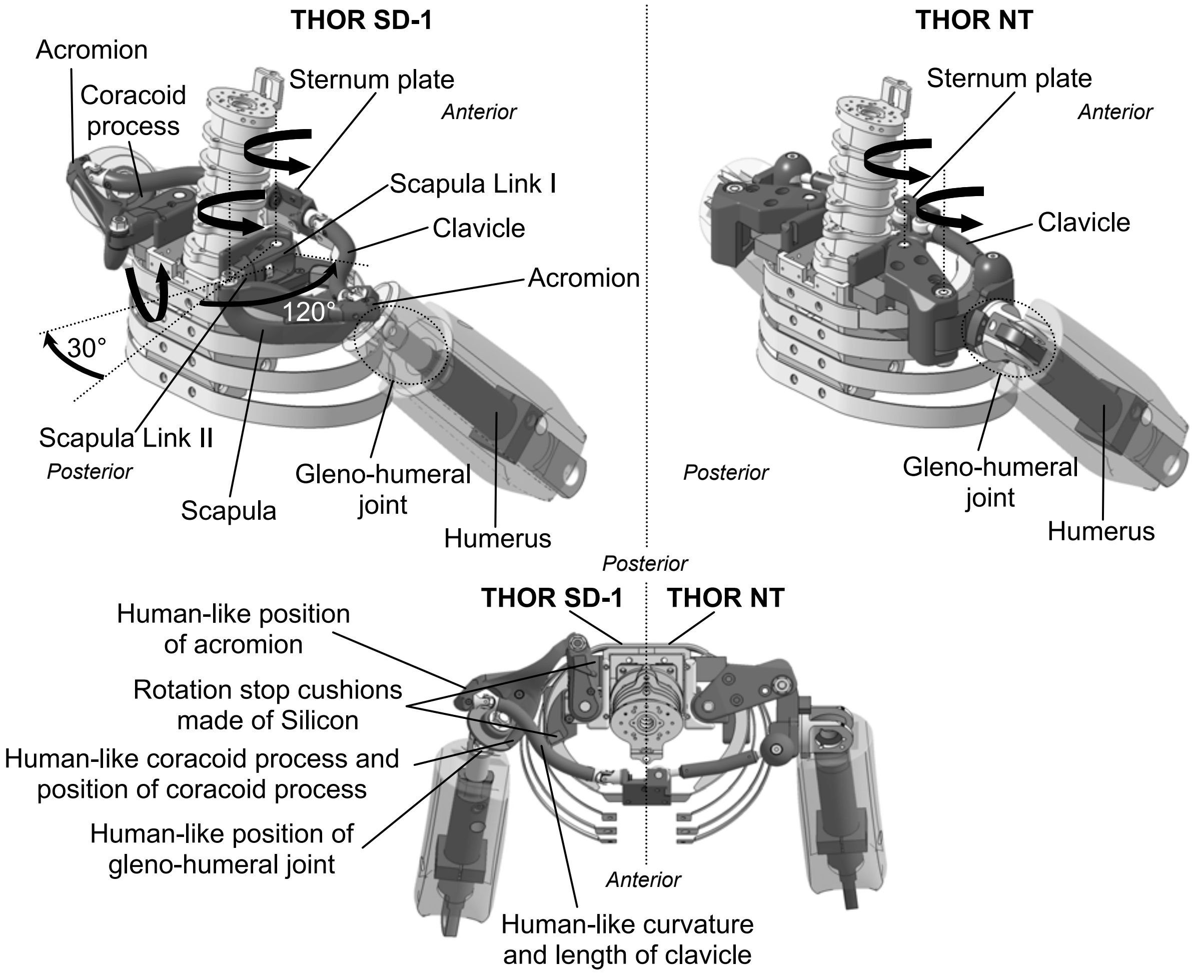


**Fig. 1 – The THOR SD-1 and the THOR NT shoulder designs, right oblique view and top view.**

RANGE-OF-MOTION STUDY: A THOR NT and THOR SD-1 were seated in a test rig while their shoulders were loaded by a pull force acting on the arms. The test set-up and procedures were the same as previously used for other dummies and volunteers by Törnvall et al. (2005). The tests were made in three pulling directions: straight forward, denoted “90° series”; diagonally-upwards, “135° series”; and upwards, “170° series”. Both shoulders were simultaneously loaded with step-wise loads. The total load ranged from 0 to 400 N/pair in 50 N increments.

## RESULTS

In this section, the range-of-motion of five volunteers, a Hybrid III (Törnvall et al., 2005), a THOR NT and a THOR SD-1 are compared under static loading conditions.

RANGE-OF-MOTION OF VOLUNTEERS, THE HYBRID III, THOR NT AND THOR SD-1: In the 90° series, the design of the THOR SD-1 allowed for approximately the same anterior shoulder motion as that of the volunteers (Figure 2A). However, in the 90° series, both the medial and superior motions of the THOR SD-1 were smaller than the volunteers' motions (Figure 2, A and B). For the 135° series, the anterior and superior motions of the THOR SD-1 were close to those of the volunteers (Figure 2A). However, the medial motion of the THOR SD-1 in the 135° series was greater than the volunteers' motion (Figure 2B). It should be noted that in the 135° series the THOR SD-1 reached the maximum motion under lower force (weight) than the volunteers did (Figure 2A). For the 170° series, the THOR SD-1 proved to have nearly the same superior motion as the volunteers (Figure 2A). However, for the 170° series the THOR SD-1 anterior and medial motions were larger than those of the volunteers (Figure 2B). Also for the 170° series the THOR SD-1 reached peak motion at a lower force (weight) than did the volunteers (Figure 2A). The Hybrid III and THOR NT shoulder designs allowed for only very limited anterior, superior and medial motions compared with the volunteers and the THOR SD-1.

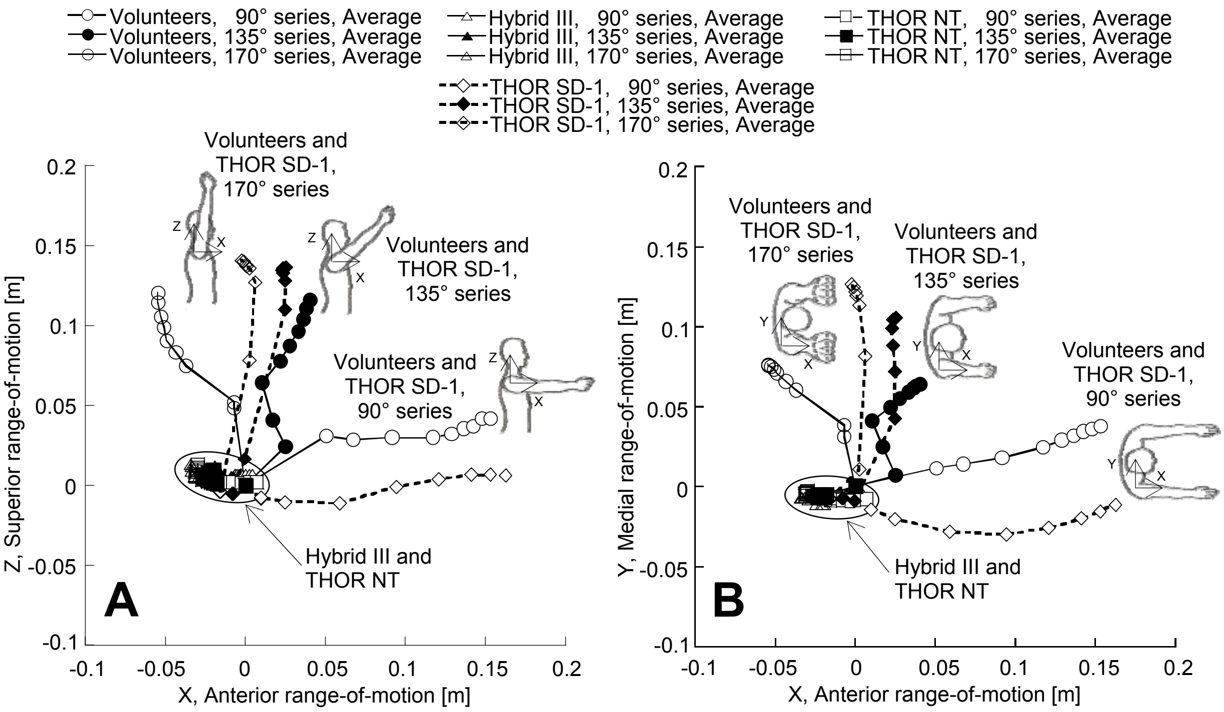


**Fig. 2 – Average shoulder motions of the volunteers, the Hybrid III, the THOR NT and the THOR SD-1 in the three test series. A: As observed from the right side, anterior-superior motion of the shoulder complex. B: As observed from above, anterior-medial motion of the shoulder complex. The point of origin for each curve represents the neutral position. The next point after the origin for each curve is when the test subject was connected to the load application cable, but before any load was applied. The remaining eight points for each curve represent an increase of 25 N/point/arm. Modified from Törnvall et al. (2005).**

## DISCUSSION

The human shoulder complex has bony landmarks e.g. the acromion and coracoid processes in combination with a curved clavicle. In our opinion, the shapes of the clavicle and coracoid process are essential structures in the dummy shoulder to ensure proper interaction of the shoulder belt with the occupant. We believe the THOR NT is more human-like than the Hybrid III in terms of bony landmarks and the presence of a clavicle structure. However, the THOR SD-1 has more advanced geometry and, thereby, a more human-like clavicle structure than the THOR NT. The human shoulder range-of-motion is mainly a combination of motions and rotations of three bones: the humerus, the scapula and the clavicle. The range-of-motion can influence the interaction with the shoulder belt and, thereby, the loading to the chest of the occupant. This motion cannot be reproduced by the Hybrid III or the THOR NT, as they have shoulder designs that allow only very limited motion (Figure 2). However, the range-of-motion of the THOR SD-1 shoulder design was in all test series a combination of anterior, posterior, medial and superior motions, in fairly good accordance with the volunteers' range-of-motion. Therefore, it is anticipated that the THOR SD-1 may also interact more like humans with a shoulder belt than the Hybrid III and THOR NT in a crash test (Figure 2). Our findings showed that the shoulder range-of-motion of the volunteers and the THOR SD-1 is larger by at least a factor of three at the maximum load (200 N/arm) than that of the Hybrid III and the THOR NT (Figure 2), independent of loading direction. However, the THOR SD-1 did not replicate exactly the volunteers' range-of-motion. A contribution to this difference could be that the dummies and the volunteers were seated with vertical torsos instead of leaning slightly rearward, and that the SD-1 is designed to produce a human-like range-of-motion in the latter position. Moreover, the superior and medial motions for series 135˚ and 170˚ of the THOR SD-1 were too large compared with the volunteers' motions (Figure 2, A and B). This may influence the shoulder, e.g. during contact with a car door, without influencing the shoulder belt interaction significantly. Furthermore, the THOR SD-1 does not reproduce the instantaneous axis of rotation (IAR) shift that takes place in the volunteers when they raise their arms during the first two or three step loadings (Törnvall et al., 2005). Although there are differences between the motion of the volunteers and the THOR SD-1, our opinion is that the shoulder motion of the THOR SD-1 is more human-like than that of the Hybrid III and THOR NT during static loadings.

## CONCLUSIONS

Two main conclusions are drawn from this comparison of the shoulder range-of-motion for volunteers, a Hybrid III, a THOR NT and a THOR SD-1 in static loading.

- The range-of-motion of the human shoulder complex during static loading was larger by at least a factor of three at the maximum load (200 N/arm, Figure 2, A and B) than that of the Hybrid III and the THOR NT.
- The range-of-motion of the THOR SD-1 shoulder complex during static loading was larger by at least a factor of three at the maximum load (200 N/arm, Figure 2, A and B) than that of the Hybrid III and the THOR NT. This indicates that the new shoulder design has the potential to function as a more human-like shoulder complex on the THOR dummy.

## FURTHER RESEARCH

Plenty of work remains before a new shoulder design is ready to be mounted on the THOR. The dynamic performance of a THOR SD-1 is currently being compared with that of cadavers. The loading conditions will be frontal, near-side and far-side. Repeatability and durability tests are also being prepared.

## ACKNOWLEDGEMENTS

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