

Biofidelity Evaluation of THOR 5th Percentile Female ATD

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ABSTRACT

THOR 5th percentile female anthropomorphic test device (ATD) was designed and one prototype ATDs was fabricated for testing to evaluate biofidelity and durability. This paper focuses on the biofidelity responses from the evaluation tests. There were total twenty three test conditions to evaluate the biofidelity responses that cover all body regions, including head, neck, shoulder, thorax, abdomen, knee-thigh-hip complex, and lower extremity. Three repeated tests were conducted on a single ATD for each test condition. The BioRank was calculated in accordance with a revised method of Rhule et al 2013. The BioRank score of most body regions was less than 2.0, corresponding to “good” biofidelity and a few less than 1.0, corresponding to “excellent” biofidelity. The overall dummy BioRank score of the dummy was less than 1.39, which corresponds to “good” biofidelity.

INTRODUCTION

The Test Device for Occupant Restraint (THOR), an advanced frontal impact 50th percentile male ATD, i.e. THOR-50M, was developed by the National Highway Traffic Safety Administration (NHTSA) to address the continued safety problem of fatalities and injuries in motor vehicles with modern restrains, such as airbag and force-limited seatbelts. The biofidelity and measurement/injury prediction capability of THOR-50M were substantially improved comparing to the Hybrid III ATD in current NHTSA regulation per Parent et al 2017. There is also a continued safety need for an advanced, small stature, frontal impact ATD. Statistical study of injuries in the field shows that female injuries differ from male due to the female’s anthropometry and anatomical differences, such as small size, low mass and cervical facet angles, etc. which change how it interacts with restraint systems and the kinematics in crash events, Parenteau 2013, Bose et al 2011 and Kahane

2013. The injury risk of the small female occupant from the seatbelt and airbag is higher. To address the small occupant safety need, THOR 5th percentile female (THOR-5F), was designed accordingly. The design was based on THOR 50M with some changes and new concepts that were described in Wang et al 2017.

Biofidelity of a test dummy is a measure of the ATD’s ability to mimic a human-like response in a crash environment. Biomechanical response requirements were established for the THOR-5F by Lee et al 2017 to both guide the design of the hardware and assess the response of the ATD. There were 23 different test conditions that covered the head, neck, shoulder, thorax, abdomen, knee-thigh-hip (KTH) and lower extremities. The purpose of this study is to evaluate the biofidelity of the THOR-5F ATD based on the three recently fabricated prototypes. The biofidelity was objectively scored using Biofidelity Ranking System (BioRank) revised from Rhule et al 2013.

METHODS

In general, the biofidelity requirements for THOR-5F were scaled from the 50th percentile male response corridors. The exception was the tibia axial impact test, in which the test response was based on 5th percentile female specimens. The scaling method and the biofidelity requirements scaled for THOR-5F are summarized in Lee et al 2017. A few changes were made from the newly available data, including the inversion/eversion dynamic test and abdomen belt test. The tests were conducted in accordance with what was outlined in Lebarbé et al 2015. The original papers cited in Lebarbé et al 2015 were used as main source for the test details. The available biofidelity corridors varied by test condition. The measurements included the standard sensors installed in THOR-5F, external displacement measured from high speed videos with 1000 fps rate and the high speed film data. The high-speed film data was analyzed with TEMA® motion analysis software. The BioRank was calculated with Matlab® script. The biofidelity corridors used for evaluation were presented as within \pm one standard deviation in order to use the biofidelity ranking technique. Time history data was evaluated for each data channel. A few tests do not have time history corridor, such as neck pendulum test, thorax pendulum test and knee slider impact. In such case, moment vs rotation or force vs deflection was used for the BioRank calculation instead. The biofidelity was assessed based on the BioRank scores in Rhule et al 2013 with modifications, which are summarized below.

1. Repetitive shift method was used instead of the cross-correlation method. The repetitive shift is to shift the test data curve until a lowest SM was achieved.
2. All data are used instead of the upper 80% data.
3. Force vs deflection and moment vs rotation were included in the BioRank calculation

The statistics meaning of the BioRank scores are summarized in Table 1.

Table 1 Biofidelity definition based on the BioRank score

Biofidelity	BioRank Score	Statistics Meaning
Excellent	$\text{BioRank} \leq 1.0$	within ± 1 SD
Good	$1.0 < \text{BioRank} \leq 2.0$	between ± 1 SD and ± 2 SD
Marginal	$2.0 < \text{BioRank} \leq 3.0$	between ± 2 SD and ± 3 SD
Poor	$\text{BioRank} > 3.0$	outside ± 3 SD

RESULTS

The head tests are head impact, face disk impact and face bar impact tests. The test data is summarized in Figure 1.

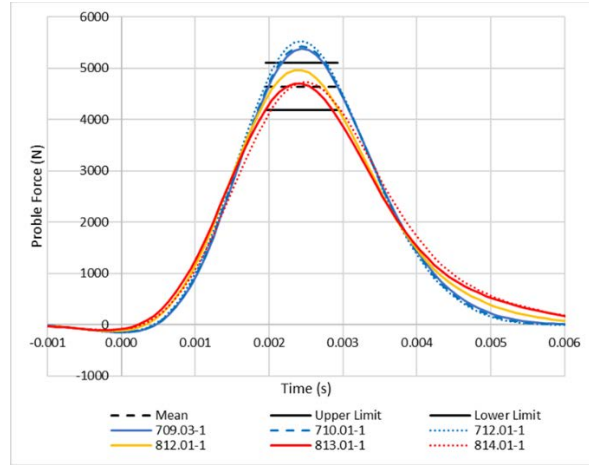


Figure 1. Head impact test result

The head impact BioRank score is 0.52, which corresponding to “good” biofidelity. The BioRank is 0.52, corresponding to “good” biofidelity.

The face disk and face bar impact test results are shown Figure 2 and Figure 3 respectively.

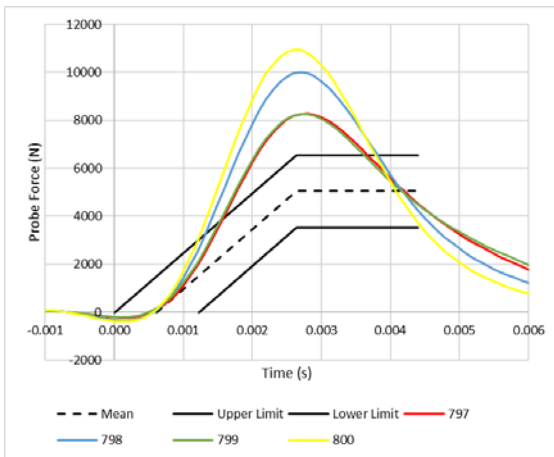


Figure 2. Face disk impact test result

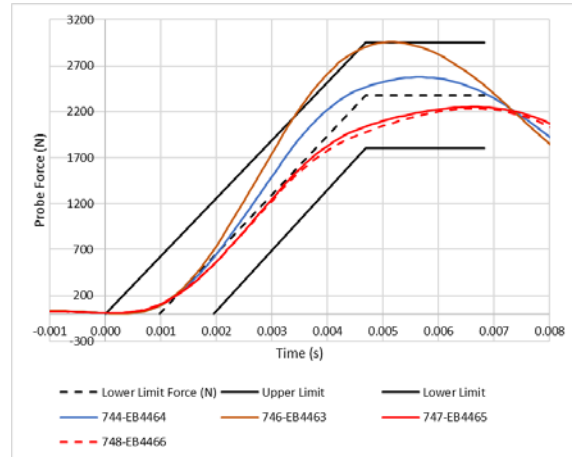


Figure 3. Face bar impact test result

The BioRank score for the face disk impact test is 1.02, corresponding to “good” biofidelity. The face bar impact test BioRank is 0.50, corresponding to “excellent” biofidelity. The BioRank scores are summarized in Table 2 and Table 3 respectively.

Table 2. Face disk impact test BioRank summary

Parameters	SM	P	RMS
Force	0.92	0.44	1.02

Table 3. Face bar impact test BioRank summary

Parameters	SM	P	RMS
Force	0.37	0.33	0.50

The neck biofidelity tests are frontal sled test and lateral sled test. The sled pulse for frontal and lateral tests are shown in Figure 4 and Figure 5 respectively.

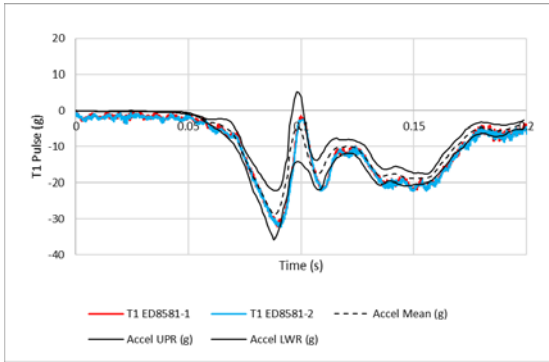


Figure 4. Frontal flexion sled test pulse

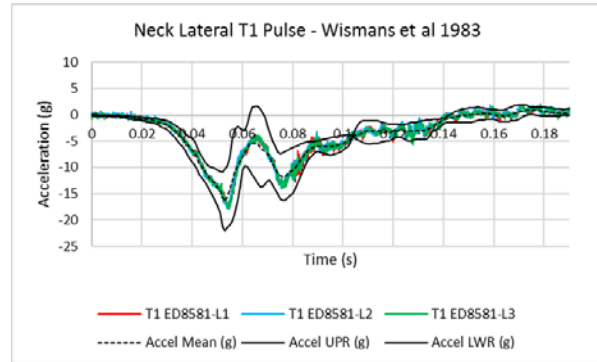


Figure 5. Lateral flexion sled test pulse

The responses of the frontal flexion and lateral flexion are shown in Figure 6 and Figure 7 respectively.

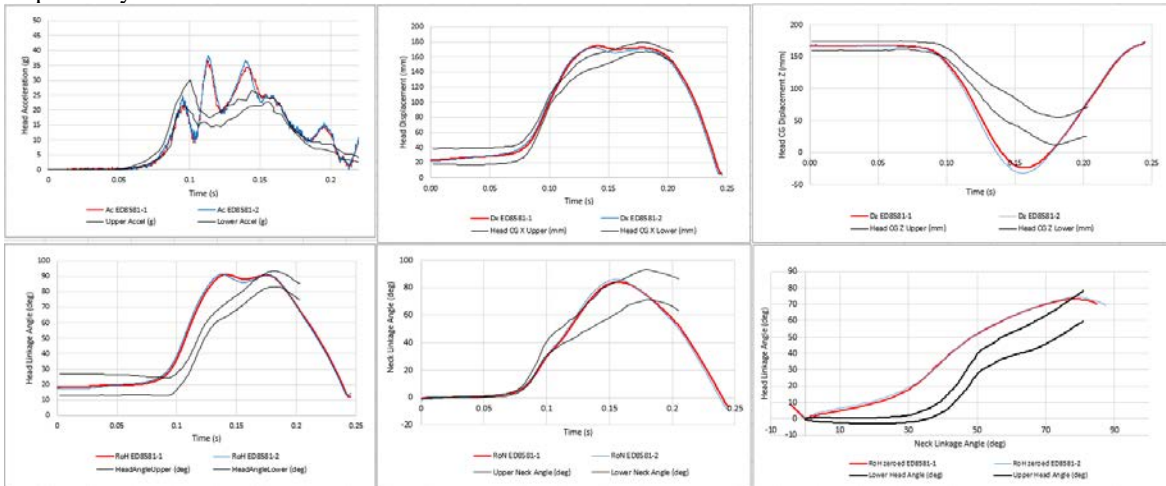


Figure 6. Responses for neck frontal sled tests

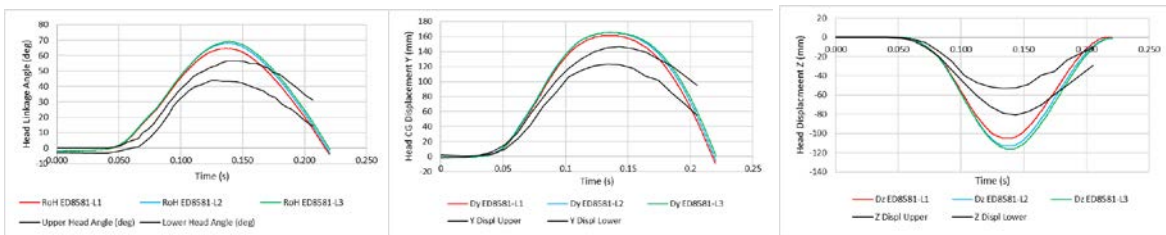


Figure 7. Responses of neck lateral flexion

The BioRank is 2.03 for the neck frontal flexion, and 2.11 for the neck lateral flexion, both corresponding to “good” biofidelity. The BioRank are summarized in Table 4. The BioRank is highlighted with yellow background for the scores higher than 2.0, with red font for scores higher than 3.0 in the table.

Table 4. BioRank summary of neck frontal sled test

Neck Sled Frontal, Thunnissen et al 1995			
Parameters	SM	P	RMS
Head Resultant Acceleration	3.06	0.34	3.08
Head Linkage Angle Y (ARS)	2.07	2.17	3.00
Head Linkage Angle Y (Video)	1.01	2.08	2.31
Neck Linkage Angle	0.99	0.53	1.13
CG Displacement X	0.86	0.42	0.96
CG Displacement Z	2.11	1.63	2.67
TC BioRank		ARS	2.17
		Video	2.03

Table 5. BioRank summary of neck lateral sled test

Neck Sled Lateral, Wismans et al 1983			
Parameters	SM	P	RMS
Head Linkage Angle Y (ARS)	1.77	0.66	1.90
Head Linkage Angle Y (Video)	1.74	0.64	1.86
CG Displacement Y	1.85	0.47	1.91
CG Displacement Z	2.55	0.21	2.56
TC BioRank		ARS	2.12
		Video	2.11

Shoulder test results for THOR 50M are shown in Figure 8. It is anticipated that THOR 5F would have similar results because the shoulder was scaled down. The BioRank is 1.07 for the THOR-50M shoulder test.

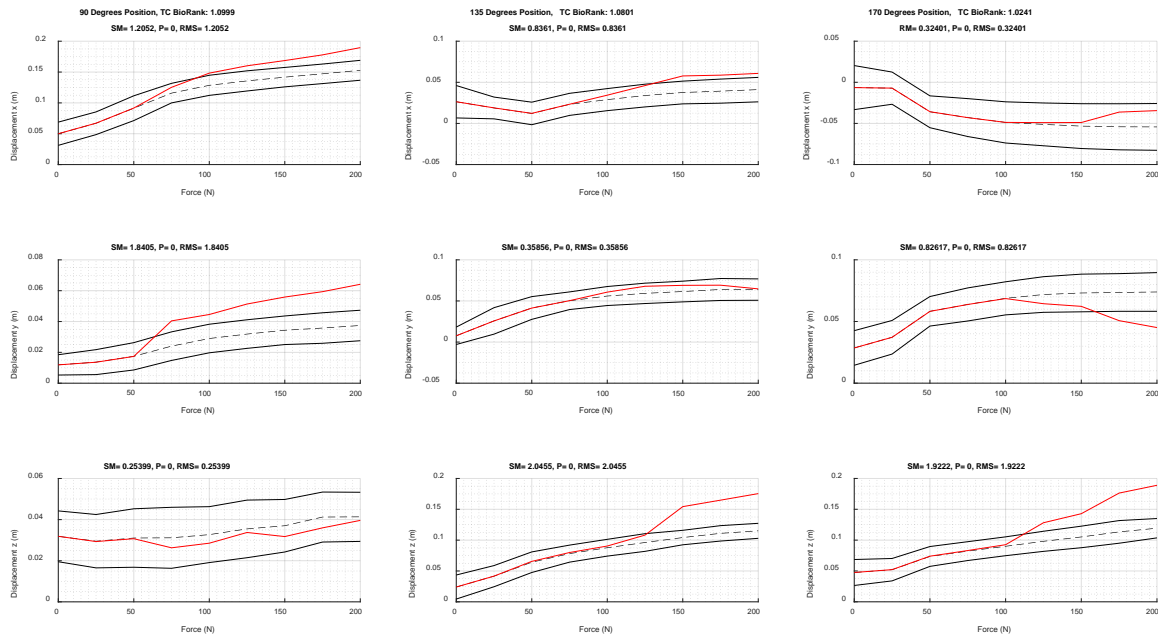


Figure 8. Response of THOR 50M shoulder test

The thorax biofidelity tests are upper thorax pendulum impact test at 4.3 m/s and oblique lower abdomen impact test. The test results for the upper thorax pendulum impact test are shown in Figure 9 and Figure 10.

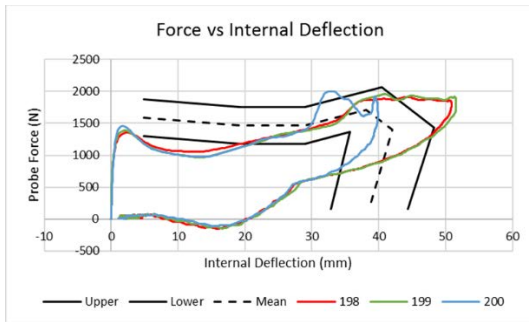


Figure 9. Probe force vs internal deflection for upper thorax impact test at 4.3 m/s

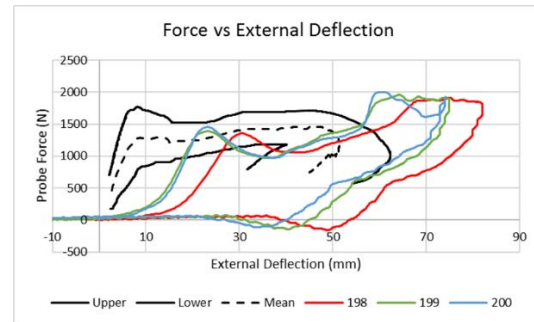


Figure 10. Probe force vs external deflection for upper thorax impact test at 4.3 m/s

The lower thorax oblique impact test result is shown in Figure 11. The deflection was measured with chestband.

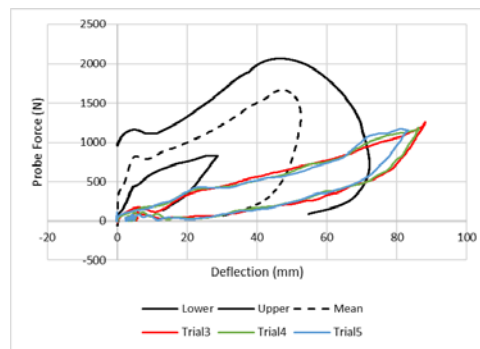


Figure 11. Probe force vs deflection for lower thorax oblique impact test

The BioRank scores for the upper thorax and oblique lower thorax impact tests are shown in Table 6 and Table 7. The upper and oblique lower abdomen tests have 1.68 and 1.46 BioRank respectively, both corresponding to “good” biofidelity. The overall thorax BioRank is 1.57, corresponding to “good” biofidelity.

Table 6. BioRank scores for upper thorax impact at 4.3 m/s

Parameters	SM	P	RMS
Internal Force vs Defl	1.13	NA	1.13
External Force vs Defl	2.08	NA	2.08
External Force	1.18	0.45	1.27
External Deflection	2.12	0.69	2.23
TC BioRank			1.68

Table 7. BioRank scores for the oblique lower thorax impact test

Parameters	SM	P	RMS
Force	1.20	0.28	1.23
Deflection	1.12	0.54	1.25
Force vs Deflection	1.90	NA	1.90
TC BioRank			1.46

The abdomen biofidelity tests are upper abdomen with steering wheel, lower abdomen test with rigid bar. The upper and lower abdomen impact test results are shown in Figure 12 and Figure 13 respectively. Abdomens with different stiffness were tested. The abdomen tests with the best BioRank score are in red color legend for both tests.

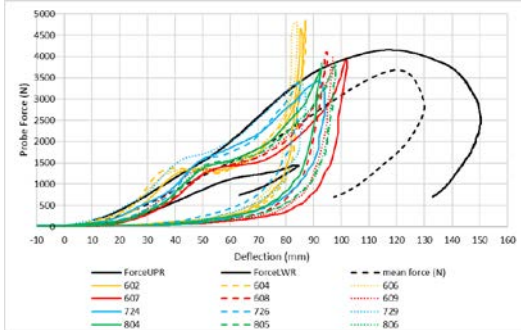


Figure 12. Upper abdomen impact test result

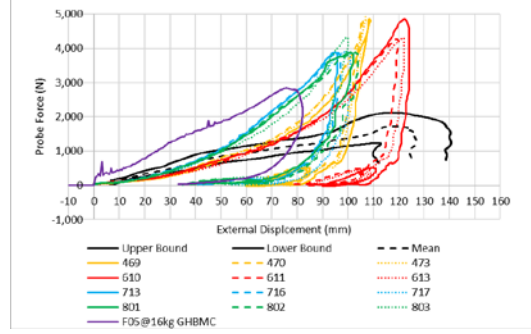


Figure 13. Lower abdomen impact test result

The abdomen BioRank for upper and lower abdomen test are summarized in Table 8 and Table 9 respectively. The upper abdomen has a BioRank 1.38, corresponding to “good”, while the lower abdomen BioRank is 3.21, corresponding to poor.

Table 8. BioRank score for the upper abdomen impact test

Parameters	SM	P	RMS
Force	1.92	1.01	2.17
Deflection	1.55	0.44	1.61
Force vs Deflection	0.35	NA	0.35
TC BioRank			1.38

Table 9. BioRank score for the lower abdomen impact test

Parameters	SM	P	RMS
Force	4.89	1.37	5.08
Deflection	0.73	0.56	0.92
Force vs Deflection	3.63	NA	3.63
TC BioRank			3.21

Knee-thigh-hip (KTH) biofidelity tests are knee slider impact test, KTH isolated and KTH full body impact tests. As of today, only the knee slider impact test was completed. The test result is shown in Figure 14. The BioRank is 0.68, corresponding “excellent” biofidelity.

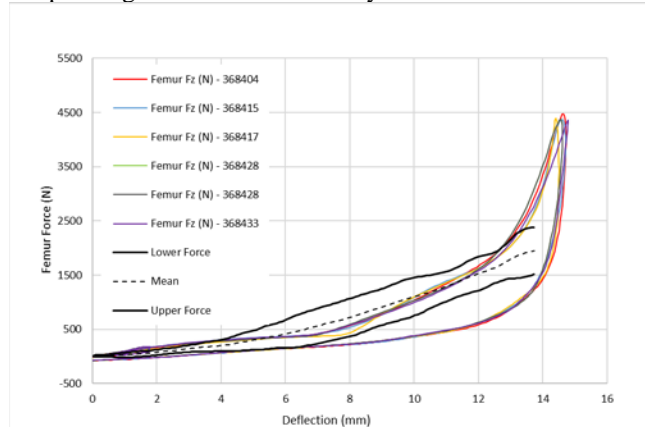


Figure 14. Knee slider impact test at 2.15 m/s

The lower extremity biofidelity tests are ball of foot impact test, tibia axial impact test, dynamic inversion and eversion test.

The ball of foot impact test result is shown in Figure 15. The BioRank score is 0.67, corresponding to “excellent” biofidelity.

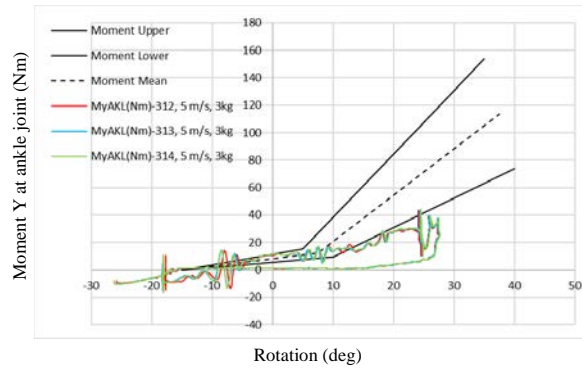


Figure 15. Ball of foot impact test

The tibia axial impact test results are shown in Figure 16 and Figure 17.

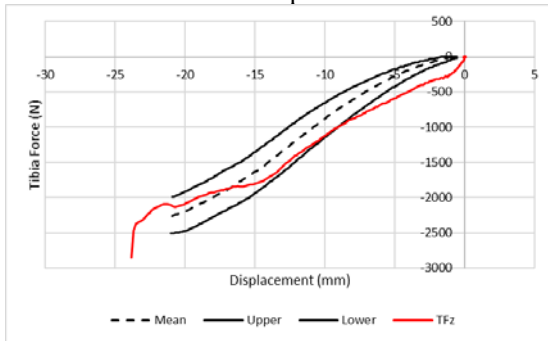


Figure 16. Tibia force vs plate displacement in tibia axial impact test

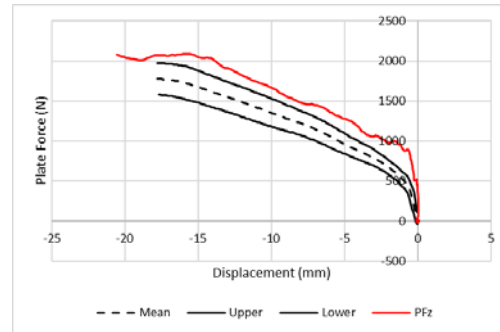


Figure 17. Plate force vs plate displacement in tibia axial impact test

The BioRank of the tibia axial impact test is shown in Table 10. The BioRank is 1.89, corresponding to “good” biofidelity.

Table 10. BioRank summary of tibia axial impact test

Parameters	SM	P	RMS
Tibia Force	4.15	1.56	4.44
Plate Force	1.10	0.25	1.13
Plate Displacement	0.76	0.28	0.81
Tibia Force vs Displacement	1.05	NA	1.05
Plate Force vs Displacement	2.02	NA	2.02
TC BioRank			1.89

The dynamic inversion and eversion test results are shown Figure 18 and Figure 19.

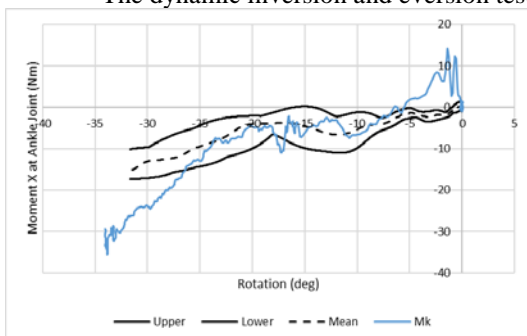


Figure 18. Result of dynamic inversion test

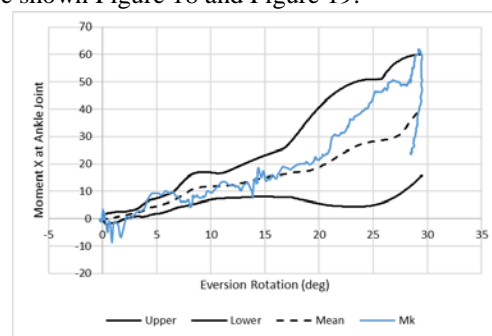


Figure 19. Result of dynamic eversion test

The dynamic inversion and eversion test BioRank are summarized in Table 10 and Table 11. The BioRank score is 1.64 for inversion, 1.30 for eversion, both corresponding to “good” biofidelity.

Table 11. BioRank summary of dynamic inversion test

Inversion, Funk et al 2002			
Parameters	SM	P	RMS
Ankle Rotation Rx	1.68	0.74	1.84
Moment at Ankle Joint	1.74	0.49	1.80
Moment vs Rotation	1.28	NA	1.28
TC BioRank			1.64

Table 12. BioRank summary of dynamic eversion test

Eversion, Funk et al 2002			
Parameters	SM	P	RMS
Ankle Rotation Rx	2.00	0.73	2.13
Moment at Ankle Joint	0.67	0.90	1.12
Moment vs Rotation	0.65	NA	0.65
TC BioRank			1.30

There are still a few test yet to be finished, for example, shoulder, KTH isolated and fully body, as the project progresses. The overall BioRank score for the test completed are shown in Table 13. The overall BioRank based on the tests completed is 1.39, corresponding to “good” biofidelity.

Table 13. BioRank summary of the dummy regions

Body Segment	Primary Requirements Only	Notes
Head	0.68	completed
Neck	2.07	completed
Shoulder	1.07	THOR 50M result, THOR 5F test in progress
Thorax	1.57	completed
Abdomen	2.30	completed
KTH	0.68	Knee slider data only, Test in progress
Lower Extremity	1.38	completed
Overall	1.39	Pending on the completion of the tests

CONCLUSIONS

THOR-5F biofidelity was evaluated under twenty three different test conditions. The overall ATD BioRank score 1.39 represents “good” biofidelity of the dummy for the tests completed. The head and KTH biofidelity are in “excellent” range, while the thorax and lower extremity are in “good” range. The ATD is ready for full scale testing evaluation, such as sled and vehicle crash tests.

ACKNOWLEDGEMENTS

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