DYNAMIC RESPONSE ANALYSIS OF THE THOR-LX DUMMY LOWER EXTREMITY

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ABSTRACT

Regarding THOR-50AM dummy lower extremities[1)] (hereafter referred to as "THOR" and "THOR-LX") developed as an assembly of lower extremities for next generation dummies in frontal impact test, we have conducted a series of tests as follows. HYGE sled tests with a toe-board simulating the impact upon intrusion into the vehicle compartment around the occupant feet, dummy dropping tests with two different postures; one is the upright posture with the knees set straight and another is the posture with the knees bent, in order to apply impact loads and to measure/evaluate the impact response characteristics. The main findings obtained through the above are as follows.

1. HYGE Sled Tests

(1) In the same impact conditions, some differences are seen by the polarity and values of tibia moment between THOR-LX and Hybrid III-50 AM dummy lower extremities (hereafter referred to as "HyIII" and "HyIII-LX").

(2) When the floor displacement rate and/or toe-board rotation angle are increased, the ankles of HyIII-LX are locked up by dorsiflexion which affects the values measured with the tibia load gauges, whereas such an effect is absent with THOR-LX.

(3) The values measured with the tibia load gauges roughly correspond with the floor/toe-board motion for THOR-LX, but the values of HyIII-LX sometimes do not correspond with the toe-board motion.

2. Dummy Dropping Tests

(1) Values of tibia axial force of THOR-LX are closer to those obtained with the volunteers (University of Heidelberg data), while those of HyIII-LX are greater.

(2) Due to differences in tibia-knee and tibia-ankle fitting locations, the values of tibia moment of HyIII-LX with inclined tibia axis become greater than those of THOR-LX with practically vertical tibia axis.

(3) Due to differences in structures of legs, ankles and feet, the pelvis acceleration peak timing with HyIII-LX is earlier than that of THOR-LX in each one of the dummy postures, and the interval from the pelvis acceleration peak timing to the tibia load peak timing is shorter with HyIII-LX.

INTRODUCTION

Research and development (R & D) of next generation dummies have been conducted in the US since 1985, with improvements and enhancements made over the conventional HyIII. Discussions on the performance requirements of impact test dummies with higher biofidelity to the human characteristics are becoming increasingly active in the frame works of ISO, SAE, EEVC, etc. Japan is also urged to conduct international joint research and cooperation in order to develop next generation dummies, etc.

Under such circumstances, JARI (Japan Automobile Research Institute) and JAMA (Japan Automobile Manufacturers Association) established the targets as described below, for the development of THOR being developed under the international joint system with the

initiative of NHTSA. JARI/JAMA are also making an active participation[2] in R & D of "easier to use next generation dummies".

(1) Identification of problems, etc. related with HyIII

(2) Collection of basic data to meet requirements of dummy design

(3) Timely feedback of improvement measures based on the above to the next generation dummy

(4) Contribution to the development of "easier to use next generation dummies"

This paper describes our evaluation results of prototype THOR-LX (lower leg + foot, the stock HyIII femur assembly was thus utilized in all tests) leased from NHTSA. THOR-LX's impact responses were compared with those of the HyIII-LX in HYGE sled tests with a movable toe-board and dummy dropping tests.

TEST METHODS

To incorporate the THOR-LX (lower extremities and feet) into the conventional HyIII, and to mount the dummy assembly onto a white body of a compact passenger car set on the HYGE sled, in order to determine the impact response characteristics of THOR-LX under impact conditions simulating the intrusion of a vehicle into the vehicle compartment near the feet.

To conduct impact tests also on the HyIII-LX under the same conditions, in order to compare the impact response characteristics between THOR-LX and HyIII-LX. (Figures 1. and 2.)

Figure 1. White body for HYGE sled test

Figure 2. THOR-LX setting condition on movable toe-board

To use pedestrian HyIII dummy in standing posture, and to hang and drop the dummy onto the floor to determine/evaluate the impact response characteristics of both THOR-LX and HyIII-Lx. (Figure 3.)

Table 1 shows the list of HYGE sled test items. The dummy is mounted on the passenger seat (driver seat with the steering assembly removed) of the white body, using the seat belt alone as the restraint system, while varying the movable toe-board travel rate for impact test.

Figure 3. Dummy in standing posture

Table 2 shows the list of dummy dropping test items. The dummy assembly was dropped from heights of 100 mm, 200 mm and 400 mm respectively from the upright position with the knees stretched and the posture with the knees bent by 30 degrees.

Table 1.
HYGE sled test items

	HYGE Sled Test No.	Dummy+LX	Restraint system	Floorpan sliding (mm)	Toepan rotation Right (deg)	Toepan rotation Left (deg)
1	TL000-4040	HyIII+THOR-LX	3P.Seatbelt	000	40(Fixed)	40(Fixed)
2	TL000-4070			000	40 ▶ 70	40 ▶ 70
3	TL100-4040			100	40(Fixed)	40(Fixed)
4	TL150-4040			150	40(Fixed)	40(Fixed)
5	TL150-4070			150	40 ▶ 70	40 ▶ 70
6	TL150-4090			150	40 ▶ 90	40 ▶ 90
7	H000-4040	HyIII+HyIII-LX		000	40(Fixed)	40(Fixed)
8	H000-4070			000	40 ▶ 70	40 ▶ 70
9	H100-4040			100	40(Fixed)	40(Fixed)
10	H150-4040			150	40(Fixed)	40(Fixed)
11	H150-4070			150	40 ▶ 70	40 ▶ 70
12	H150-4090			150	40 ▶ 90	40 ▶ 90

Table 2.
Dropping test items

	Dropping test Test No.	Dummy+LX	Posture	Drop height (mm)
1	TLD101	HyIII+THOR-LX	Knees stretched	100
2	TLD102			100
3	TLD201			200
4	TLD202			200
5	TLD401			400
6	TLD402			400
7	TLDA101		Knees bent by 30 deg	100
8	TLDA102			100
9	TLDA201			200
10	TLDA202			200
11	TLDA401			400
12	TLDA402			400
13	HYD101	HyIII+HyIII-LX	Knees stretched	100
14	HYD201			200
15	HYD401			400
16	HYDA101		Knees bent by 30 deg	100
17	HYDA201			200
18	HYDA401			400
19	HYDA404			400

TEST RESULTS

HYGE sled tests using THOR-LX and HyIII-LX have been conducted 12 times according to the difference in toe-board activating conditions.

Regarding the dummy dropping tests, only data of

Table 3.
Measured values of lower extremities

Test No.	Tibia Upper						Tibia Lower					
	FX kN		FZ kN		MY Nm		FX kN		FZ kN		MY Nm	
	R	L	R	L	R	L	R	L	R	L	R	L
TL000-4040	0.463	0.552	-1.634	-1.248	-46.5	53.5	-0.379	-0.385	-1.809	-1.566	-39.5	-30.3
TL000-4070	0.506	0.753	-1.369	-1.412	-80.9	52.2	-0.637	-0.524	-1.706	-1.689	-65.2	-40.4
TL100-4040	0.397	0.355	-1.640	-1.389	-53.7	43.1	-0.396	-0.411	-2.043	-1.954	-36.9	-29.8
TL150-4040	0.321	0.549	-1.543	-1.439	-57.5	60.2		-0.420	-1.916	-1.948	-32.4	-31.7
TL150-4070	0.358	0.622	-1.396	-1.626	-75.4	56.3	-0.557	-0.448	-1.780	-2.039	-55.5	30.7
TL150-4090	0.298	0.372	-1.511	-1.478	-69.4	-45.0	-0.536	-0.512	-1.806	-2.100	-55.4	-43.0
H000-4040	-0.470	-0.475	-2.358	-2.132	-71.3	67.3	-0.611	-0.449	—	—	-20.7	-18.7
H000-4070	-0.368	-0.312	-1.700	-1.759	-81.3	-61.0	-0.652	-0.390	—	—	-33.7	31.3
H100-4040	-0.159	0.464	-1.046	-1.224	-59.8	65.9	-0.388	-0.353	-1.302	-1.465	-20.7	-15.5
H150-4040	-0.306	0.504	-1.705	--1.434	-76.1	97.8	-0.496	-0.449	-2.090	-1.710	-26.1	-24.1
H150-4070	-0.224	-0.217	-1.287	-1.485	-92.5	64.9	-0.706	-0.461	-1.698	-1.801	-34.0	44.6
H150-4090	-0.458	-0.499	-1.264	-1.340	-84.3	99.4	-0.630	-0.471	-1.593	-1.609	117.0	131.6

pelvis, lower extremities and dummy motions have been analyzed.

Measured Values of Lower Extremities in HYGE Sled Tests

Tibia Axial Force Table 3 shows the measured values of lower extremities. The comparison of axial force FZ at the tibia upper portion between HyIII-LX and THOR-LX shows that the axial force of THOR-LX is 1.5 kN or so, but the force varies from 1 kN to 2.4 kN or so for HyIII-LX. (Figure 4.)

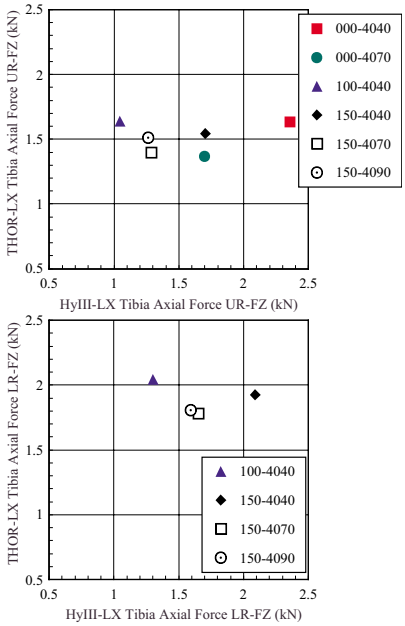

Figure 4. Comparison of tibia upper and lower axial force

A similar comparison of axial force at the tibia lower portions shows that it is about 2 kN for tibia with THOR-LX, and it is about 1.3 to 2 kN with HyIII-LX though the variation is smaller than that of the upper portions. It is deduced that the roughly constant difference of force between the upper and lower portions and the roughly constant force value are due to the influence of the Achilles tendon and some inertial effect.

The tibia maximum axial force occurs around 40 ms which is earlier than the floor/toe-board activation timing in all cases, without showing any correlation with the activation conditions.

Tibia Moment The comparison of moment around the Y-axis of tibia upper portions between HyIII-LX and THOR-LX shows that the values of HyIII-LX are greater for both right and left tibia. By comparing the values of right tibia in terms of toe-board activated conditions, it is found that the moment becomes greater by rotating the toe-board rather than moving the floor.

As for the left tibia, no correlations is found with the toe-board activated conditions. (Figures 5. and 6.)

The values of tibia lower moment tend to become greater with THOR-LX. In case of HyIII-LX, however, no correlation with the toe-board operation can be observed, as the maximum moment occurs where the ankle are locked up and the calf is pressed down around the seat cushion front edge when the floor moves or toe-board angle changes by a large amount. (Figures 7., 8. and 9.) Therefore, it is decided that such a comparison be made while taking account of the toe-board activation timing.

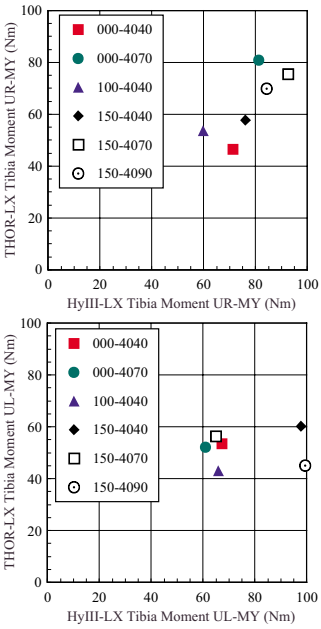

Figure 5. Comparison of moment MY at tibia upper portion

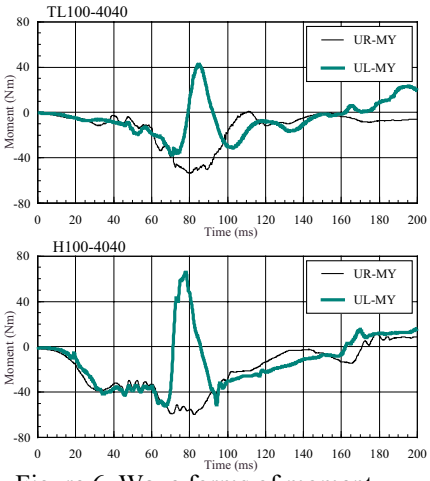

Figure 6. Wave forms of moment MY at tibia upper portion

It is also decided that the comparison be made in tibia on the right side, since the left knee alone collides against the instrument panel, and the polarity of moment reverses by the impact. The comparison of moment around the Y-axis at the right-hand tibial lower portion done as described above reveals that the moment becomes larger by the rotation of toe-board as in the case of MY on the upper portion. (Figure 10.)

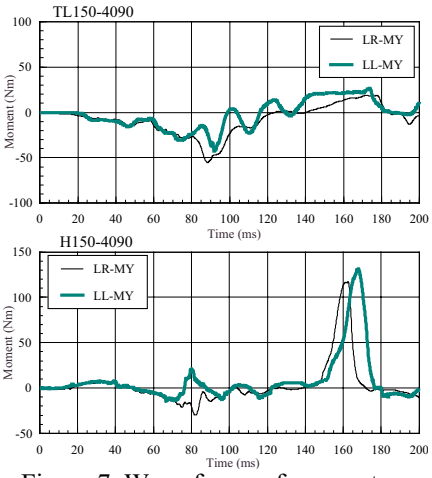

Figure 7. Wave forms of moment MY at tibia lower portion

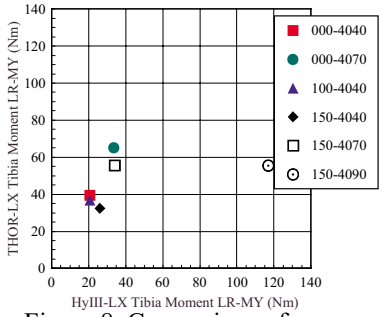

Figure 8. Comparison of moment MY at tibia lower portion

The comparison of the values between the tibia upper and lower portions of each set of lower extremities shows a greater difference with HyIII-LX - that is, the values at the upper portion are 1.2 to 1.8 times greater than those at the lower portion. The MY at the lower portion of HyIII-LX in particular is smaller than the values of others. It is presumably due to the ankle structure of HyIII-LX which consists of a mere ball joint at which a great moment is not likely to occur unless the ankle is locked. (Figure 11.)


Figure 9. Locked condition of HyIII-LX ankle

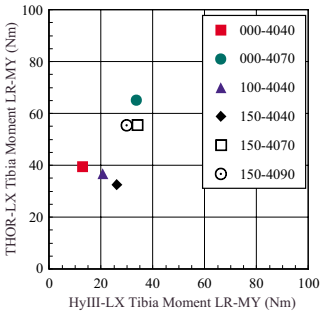

Figure 10. Comparison of tibia lower moment MY

Tibia Index The tibia index (hereafter referred to as "TI") is affected more by the moment than the axial force of tibia. Therefore, the timing of occurrence of the maximum value coincides with that of the maximum value of MY in most cases. Table 4. shows the values of TI.

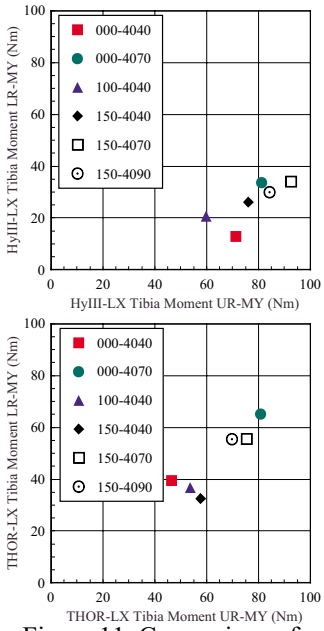

Figure 11. Comparison of moment MY between tibia upper and lower portions

Table 4.
Tibia index

Test No.	Tibia Index			
	Tibia Upper		Tibia Lower	
	R	L	R	L
TL000-4000	0.222	0.269	0.269	0.145
TL000-4070	0.377	0.264	0.324	0.206
TL100-4000	0.242	0.226	0.184	0.144
TL150-4000	0.264	0.328	0.159	0.165
TL150-4070	0.365	0.281	0.279	0.174
TL150-4090	0.332	0.228	0.281	0.255
H000-4000	0.371	0.348	0.110	0.111
H000-4070	0.373	0.320	0.159	0.141
H100-4000	0.282	0.309	0.112	0.097
H150-4000	0.362	0.450	0.147	0.142
H150-4070	0.441	0.326	0.190	0.216
H150-4090	0.402	0.447	0.534	0.598

The comparison of TI at the tibia upper portion reveals the general tendency that the values of HyIII-LX are generally greater. The tendency that the TI value becomes greater by rotating the toe-board is the same as that of MY. Regarding the left tibia, on the other hand, the knee collides against the lower portion of instrument panel in most cases and the polarity of moment changes suddenly at that time. Therefore, the tendencies of toe-board motion and the TI values become different from each other.

The comparison of TI at the lower portions of tibiae shows that the TI values of HyIII-LX become extremely great as the feet move markedly backward, due the increased amount of floor displacement and the rotation of toe-board, resulting in the state described earlier, and the occurrence of a greater moment.

Measured Values of Pelvis and Lower Extremity in Dummy Dropping Tests

Pelvis Acceleration The comparison of accelerations in pelvis Z-axial direction between HyIII-LX and THOR-LX shows that the values of HyIII-LX are generally greater than those of THOR-LX, which are 1.7 to 2.5 times greater in the posture of straight knees and 1.6 to 1.2 times greater in the posture of bent knees. The comparison in terms of posture shows that the values in knees straight posture are 2 to 2.5 times greater than those with the knees bent with HyIII-LX, and 1.5 to 2.1 times greater with THOR-LX. (Table 5.)

Table 5. Pelvis acceleration

Test No.	Pelvis Max. Z-Acc. m/s^2 (msec)
TLD101	97 (29.7)
TLD102	87 (26.5)
TLD201	132 (20.6)
TLD202	123 (19.7)
TLD401	228 (17.9)
TLD402	232 (18.3)
TLDA101	57 (48.8)
TLDA102	57 (52.2)
TLDA201	72 (40.8)
TLDA202	67 (42.1)
TLDA401	110 (28.0)
TLDA402	132 (27.8)
HYD101	165 (13.5)
HYD201	303 (14.4)
HYD401	519 (10.3)
HYDA101	81 (39.8)
HYDA201	153 (30.4)
HYDA401	219 (19.4)
HYDA402	208 (25.6)

The comparison of wave forms of acceleration shows that the accelerations start earlier and rise more sharply for HyIII-LX in each posture.

Tibia Axial Force There are differences in tibia-knee and tibia-foot fitting methods/conditions between HyIII-LX and THOR-LX. In addition, there are structural difference of the tibia of HyIII-LX having an inclination, and in THOR, the straight tibia adds the Achilles tendon, which cause the difference in values of axial force. In the tibia of HyIII-LX used for present test, axial force can be measured only in the upper portion.

Therefore, the comparison of tibia axial forces between the HyIII-LX and THOR-LX used in the evaluation tests can be done only for the axial forces measured with the upper load gauges. In both dummy postures, the values are greater with HyIII-LX by twofold. (Table 6.)

The rise of load is also sharper with HyIII-LX. Those differences are presumably due to the structural differences. Namely, the ankles of HyIII are connected with metallic ball joints, while those of THOR-LX are utilizing the torsion of rubber at the joints. The compliance elements incorporated in the tibia of THOR-LX to reflect human characteristics and the difference in sole hardness also appear to have influenced the measured results. (Fig. 12.)

The differences in axial force due to the difference in posture are as follows. The knees straight posture shows

Table 6.
Measured values of lower extremities

Test No.	Tibia Upper FZ kN R	Tibia Upper FZ kN L	Tibia Upper MY Nm R	Tibia Upper MY Nm L	Tibia Lower FZ kN R	Tibia Lower FZ kN L	Tibia Lower MY Nm R	Tibia Lower MY Nm L
TLD101	-2.296	-2.729	37.5	37.1	-2.388	-3.048	11.2	-52.1
TLD102	-2.197	-2.661	34.5	27.4	-2.278	-2.939	14.4	12.1
TLD201	-3.296	-3.914	47.3	52.2	-3.422	-4.373	16.3	-82.1
TLD202	-3.253	-3.837	53.2	48.8	-3.447	-4.208	18.9	17.2
TLD401	-5.821	-6.234	81.6	81.6	-6.129	-6.831	32.2	-104.9
TLD402	-5.724	-6.391	75.4	83.6	-6.131	-6.957	32.1	34.8
TLDA101	-1.394	-2.115	-14.8	-18.1	-1.831	-2.711	8.6	12.5
TLDA102	-1.638	-1.850	-11.9	-16.7	-2.024	-2.517	14.4	14.8
TLDA201	-2.168	-2.841	-21.0	-24.4	-2.657	-3.550	16.7	14.5
TLDA202	-2.204	-2.563	-20.1	-21.9	-2.632	-3.303	17.9	17.8
TLDA401	-2.968		-34.1	-40.4	-3.628	-4.774	21.4	30.6
TLDA402	-3.127	-3.572	-34.4	-30.9	-3.650	-4.494	31.0	30.3
HYD101	-4.398	-4.891	-100.8	-106.3	—	—	42.5	52.1
HYD201	-7.287	-7.661	-148.0	-165.4	—	—	67.9	82.1
HYD401	-11.536	-11.426	-204.2*	-205.7*	—	—	101.6	104.9
HYDA101	-2.543	-2.750	-82.6	-96.1	—	—	31.0	22.6
HYDA201	-4.648	-4.503	-148.5	-133.0	—	—	51.1	46.7
HYDA401	-6.464	-7.211	-202.5	-202.6*	—	—	70.6	70.3
HYDA402	-5.584	-6.065	-175.8	-178.3	—	—	63.9	60.9

greater values than those in posture with the knees bent - about 1.8 times greater at the upper portion of HyIII-LX, twice or so greater at the upper portion of THOR-LX, and about 1. 7 times greater at its lower portion .(Table 6. and Figure 13.)

The differences in axial forces of THOR-LX between the upper and lower portions are as follows. Assuming that the axial force at the lower portion is 1, the axial force at the upper portion is 0.95 with straight knees and 0.82 with bent knees. The differences in upper and lower tibia axial force are presumably due to inertial effect of the mass between the upper and lower tibial load gauges and the Achilles tension effect.

Tibia Moment As for the tibia moment, MX values around the X-axis and MY values around the Y-axis can be measured at the upper and lower portions for both HyIII-LX and THOR-LX, but the comparison is made on MY here, since their leg structures are different from each other.

As well as the case of axial force, the moment peak values of HyIII-LX are greater by 3 to 5 times than those of THOR-LX in all cases. The values in knees straight posture tend to become greater than those with the knees bent. (Table 6., Figures 14. and 15.)

In case of HyIII-LX, the values at the upper portion are greater by 2 to 2.8 times than those at the lower portion. In case of THOR-LX, the values at the upper portion are

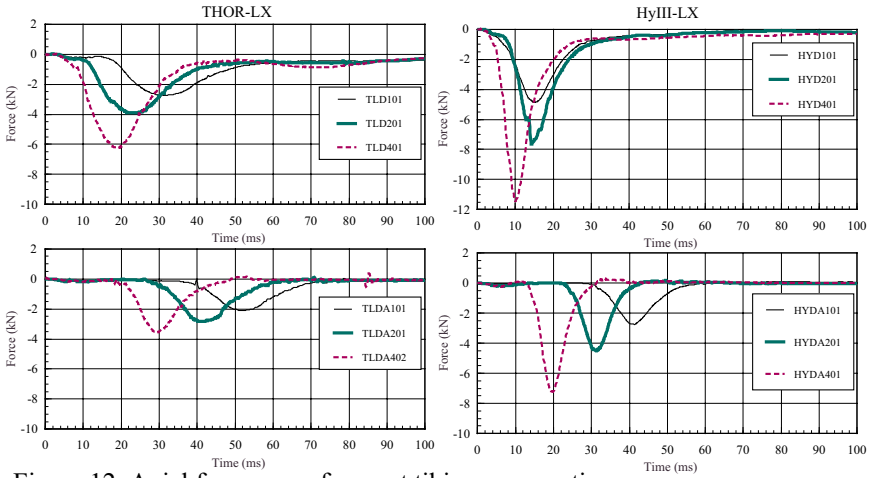

Figure 12. Axial force wave forms at tibia upper portion

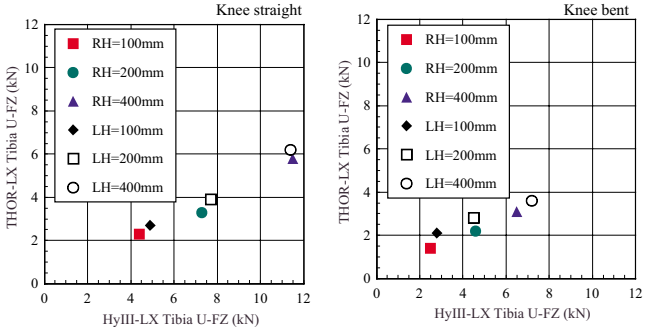

Figure 13. Comparison of axial force FZ at tibia upper

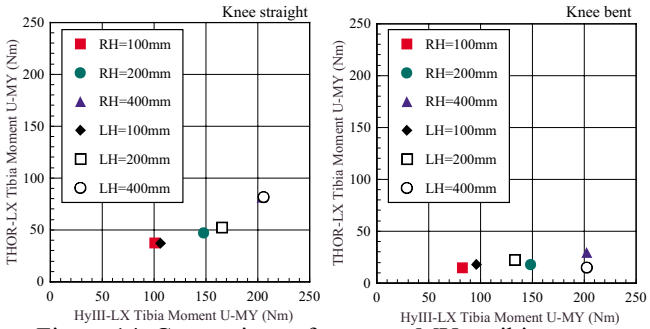

Figure 14. Comparison of moment MY at tibia upper portion

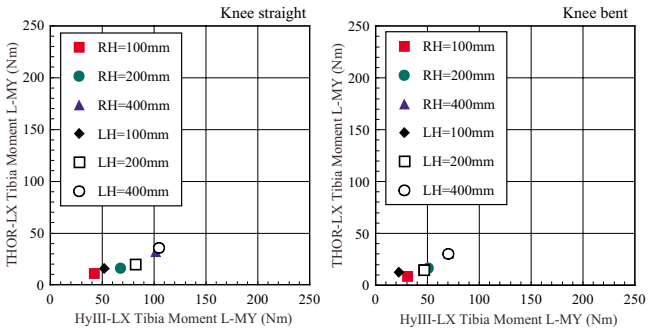

Figure 15. Comparison of moment MY at tibia lower portion

greater by 2.5 times than those at the lower portion in knees straight posture, though the polarity of wave form is plus for both of them. With the knees bent, the wave forms of upper and lower portions do not show any significant peak.

In case of HyIII-LX, each tibia inclines slightly forward in the leg flesh and the upper load gauge is located further forward than the lower load gauge, as the upper end of tibia is installed in the forward direction relative to the knee rotation center. Moreover, the ankle ball joint is located at the lower end of tibia bent slightly forward. All of the above constitute a structure with which MY tends to occur relatively easily.

In case of THOR-LX, the upper end of tibia is so fixed to coincide with the knee rotation center, and the ankle rotation center also coincides with the tibia lower end. Thus the upper and lower load gauges are located on the same axis, constituting a structure with which the occurrence of MY becomes relatively difficult compared with HyIII-LX. (Figure 16.)

Furthermore, when an ankle of THOR-LX is dorsiflexed, the occurrence of MY on the plus side is suppressed by the function of Achilles tendon at the location of tibia lower load gauge. In case where the knees are bent in particular, the dummy assembly tends to bend backward when it hits the ground. It is therefore deduced that the posture with the bent knees tends to be affected by the Achilles tendon more than the case with straight knees.

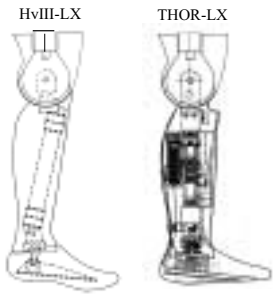

Figure 16. Lower extremity structure

Tibia Index Using the data of the lower extremities of two dummy assemblies with the differences described in the foregoing, we have calculated the values of

Tibia Index (TI) proposed as the injury index.

The comparison of the values calculated from the values measured with the tibia upper load gauges shows that the maximum values of both the knees straight posture and the knees bent posture are 1.0 or greater with HyIII-LX, while those with THOR-LX are 0.6 in the knees straight posture and 0.3 with the knees bent posture, showing great differences between the two types of dummy assemblies. (Table 7.) When each dummy assembly was dropped in knees straight posture, the TI value of upper portion becomes greater in proportion to the increase in dropping height regardless of the type of dummy assembly. When the dummies were dropped in the knees bent posture, the above mentioned tendency was found with HyIII-LX but absent for THOR-LX. (Figure 17.)

Table 7.
Tibia index

Test No.	Tibia Index			
	Tibia Upper		Tibia Lower	
	R	L	R	L
TLD101	0.232	0.299	0.113	0.153
TLD102	0.216	0.226	0.121	0.133
TLD201	0.310	0.378	0.164	0.211
TLD202	0.331	0.338	0.179	0.192
TLD401	0.528	0.559	0.315	0.358
TLD402	0.512	0.550	0.312	0.352
TLDA101	0.108	0.258	0.074	0.148
TLDA102	0.079	0.169	0.117	0.139
TLDA201	0.176	0.346	0.146	0.184
TLDA202	0.128	0.266	0.147	0.181
TLDA401	0.163		0.184	0.268
TLDA402	0.173	0.230	0.239	0.260
HYD101	0.552	0.601	0.313	0.368
HYD201	0.840	0.961	0.503	0.578
HYD401	1.228*	1.259*	0.756	0.781
HYDA101	0.439	0.533	0.209	0.198
HYDA201	0.789	0.720	0.354	0.332
HYDA401	1.081	1.114*	0.480	0.513
HYDA402	0.938	0.980	0.429	0.443

*saturated

The comparison of TI values of tibia lower portions shows that the values of HyIII-LX are greater than those of THOR-LX as in the case of TI values at the upper portions. That is, the values of HyIII-LX are about 2.6 times greater than those of THOR-LX in knees straight posture, and about 2.1 times greater in knees bent posture. The TI values of tibia lower portions tend to become greater in proportion to the increase of dropping height for both HyIII-LX and THOR-LX.

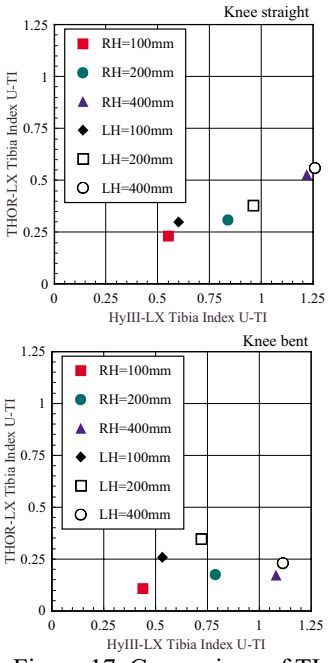

Figure 17. Comparison of TI values at tibia upper portion

In case of the HyIII-LX used in our tests, the axial force could be measured only at the upper portions. Therefore, the axial force that could be measured and the moment measured at the lower portions are used here to calculate the TI values. As the tibia axial force generally becomes greater at the lower portions, it is anticipated that the TI values of HyIII-LX lower portions become somewhat smaller than in other cases.

The comparison of TI values of THOR-LX between the upper and lower portions per posture reveals that the TI value of upper portion is greater by 1.9 times than that of lower portion at each dropping height in the knees straight posture. With the knees bent, however, the tendency of upper TI values is not constant as stated earlier.

Comparison of Data with those of Heidelberg University

The current dummy dropping test data are compared with the test data[4] on dummies and volunteers conducted and obtained by Heidelberg University.

Tibia Axial Force As stated earlier, tibia axial forces have been measured only at the upper portions in this series of tests, whereas only the lower portion axial forces are described in the data of Heidelberg University. Therefore, four kinds of data - JHyA-U (test data of HyIII-LX tibia upper portions with the knees bent obtained in this series of tests), TLA-U (test data of THOR-LX tibia upper portions with the knees bent obtained in this series of tests), TLA-L (test data of THOR-LX tibia lower portions with the knees bent, obtained in this series of tests), and HHyA-L (test data of HyIII-LX tibia lower portions with the knees bent, obtained by Heidelberg University) - are compared here.

Despite the difference in measured locations, the values of HyIII-LX axial force are similar with each dropping height. The values of THOR-LX are smaller than those of HyIII-LX at both upper and lower portions. Namely, the comparison with the dropping height of 400 mm shows that the axial force of HyIII-LX is 6.5 kN or so while that of THOR-LX lower portion is about 4.2 kN

and that of the upper portion is about 3.3 kN, showing significant differences among them. (Figure 18)

Load gauges were attached to the shoe soles in the dropping tests conducted by Heidelberg University, and loads that occurred around the heels of dummies and volunteers were also measured. It is stated in the report that the measured axial forces of dummies at their tibia lower portions and the loads applied to the heels are roughly equal. With a dropping height of 400 mm or so, the values of HyIII-LX exceed the values of volunteers

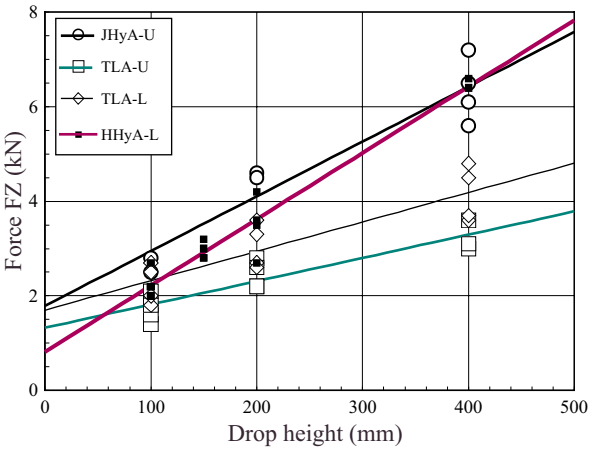

Figure 18. Comparison of tibia axial force

markedly, losing biofidelity to human characteristics.

The comparison of the tibia lower axial force of THOR-LX measured in our current tests and those of the volunteers measured by Heidelberg University shows some similarities between the values measured with THOR-LX and the values of the volunteers around their upper limits, though the values of volunteers vary significantly. Although no definite conclusion can be drawn from those data alone, it may be considered that the biofidelity is improved in terms of tibia impact response characteristics. (Figure 19.)

Tibia Index A similar comparison of TI with the knees bent shows that the values of JHyA-U (described earlier) are the greatest at all dropping heights, followed by those of HHyA-U (Heidelberg University tests on HyIII-LX tibia upper portion with the knees bent) and JHyA-L (our current tests on HyIII-LX tibia lower portion with the knees bent) in that order. The values of TLA-U (described earlier) and TLA-L (also described earlier) are even

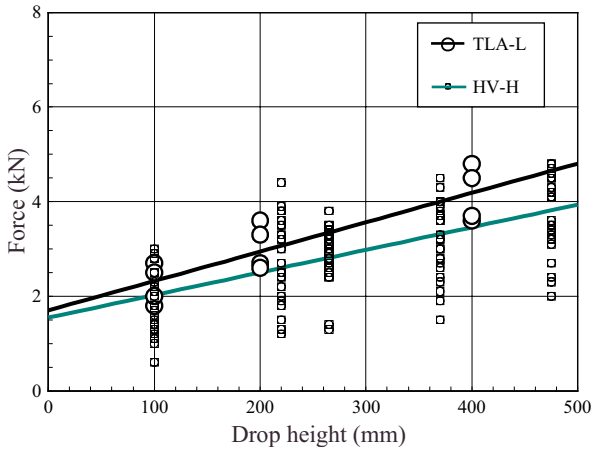

Figure 19. Comparison of tibia axial force and heel force

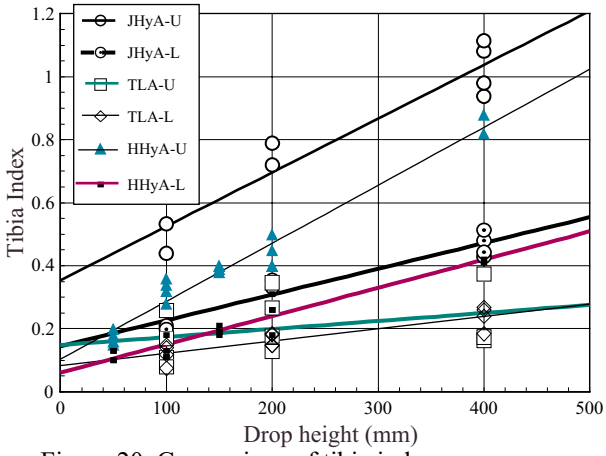

Figure 20. Comparison of tibia index

smaller than those of HyIII-LX tibia lower portion. (Figure 20.)

Different from the tibia axial forces, the TI values of the tibia upper portions are greater than those of lower portions, which are due to the greater values of moment measured at the upper portions.

CONCLUSIONS

Regarding THOR-LX developed as an assembly of lower extremities for next generation dummies in frontal impact test, we have conducted a series of tests as follows. HYGE sled tests with a toe-board simulating the impact upon intrusion into the vehicle compartment around the occupant feet, dummy dropping tests with two different postures; one is the upright posture with the knees set straight and another is the posture with the knees bent, in

order to apply impact loads and to measure/evaluate the impact response characteristics. The main findings obtained through the above are as follows.

HYGE Sled Tests

(1) Some differences are found in polarity and values of tibia moment under the same impact conditions between THOR-LX and HyIII-LX.

(2) The description to this report was omitted but the difference in polarity of longitudinal shear force is found in the initial phase of impact.

(3) When the floor displacement rate and/or toe-board rotation angle are increased, the ankles of HyIII-LX are locked up by dorsiflexion which affects the values measured with the tibia load gauges, whereas such an effect is absent with THOR-LX.

(4) The values measured with the tibia load gauges roughly correspond with the floor/toe-board motion for THOR-LX, but the values of HyIII-LX sometimes do not correspond with the toe-board motion.

(5) The axial force at THOR-LX tibia upper portion becomes roughly constant, whereas a maximum difference of 1.3 kN or so is found in the values of HyIII-LX.

(6) The dorsiflexion characteristics of THOR-LX are adjusted by means of ankle structure and Achilles tendon, which are different from those of HyIII-LX with the ankles made of ball joints. Therefore, there are some differences in the motions around ankles upon impact.

Dummy Dropping Tests

(1) Values of axial force of THOR-LX are closer to those obtained with the volunteers, while those of HyIII-LX are greater.

(2) Due to differences in tibia-knee and tibia-ankle fitting locations, the values of tibia moment of HyIII-LX with inclined tibial axes become greater than those of THOR-LX with practically vertical tibial axes.

(3) Due to differences in structures of legs, ankles and feet, the pelvis acceleration peak timing with HyIII-LX is earlier than that of THOR-LX in each one of the dummy postures, and the time from the pelvis acceleration peak timing to the tibial load peak timing is shorter with HyIII-LX.

(4) On the evaluation of the lower leg injury by TI, there were no injured volunteers in the Heidelberg university tests, while HyIII-LX generated TI's greater than 1 and it is necessary to examine further.

(5) Due to the Achilles tendon attached to THOR-LX, the motions around ankles become different from those of HyIII-LX.

ISSUES TO BE CONSIDERED and DEALT WITH

We have incorporated the THOR-LX being developed as an assembly of lower extremities for next generation dummies into HyIII and conducted a series of tests for evaluation of impact response characteristics in comparison to those with HyIII-LX. HYGE sled tests with a toe-board installed, and dummy dropping tests to drop dummies from specified heights have been conducted to apply impact loads in both types of the tests to measure and evaluate the impact response characteristics.

Issues to be considered and dealt with in coming years are as follows.

(1) Tibia injury index TI values are presently calculated from the values measured with the load gauges for HyIII-LX. However, the values of moment tend to become greater with THOR-LX as described earlier, resulting in greater TI values as well. Such differences in moment are related closely with the differences in tibia-knee and tibia-ankle fitting methods as well as their structures. Closer conformity to human characteristics is necessary.

(2) Motions around ankles are different between HyIII-LX and THOR-LX, as Achilles tendon are attached to the latter and the ankle structure is also different from the ball-joint type ankles of HyIII-LX, which also call for further studies in terms of conformity/fidelity to the human characteristics.

(3) The test results of tibia axial force of THOR-LX are closer to those of the tests on volunteers, which appears to indicate relatively high practicability of THOR-LX in terms of biofidelity. In the HYGE sled tests, however, the values of axial force of THOR-LX are greater than those of HyIII-LX in some cases. It is considered that in addition, the examination will be needed on the difference

of both test results in future.

CONCLUDING REMARKS

An assembly of lower extremities named "THOR-LX", out of various THOR assemblies for next generation dummies being developed with international joint efforts, was leased out to us, and we have conducted tests to evaluate the impact response characteristics of the lower extremities accordingly. We have also tested HyIII-LX under the same test conditions for comparison and analysis of the assemblies.

The THOR dummy was designed by General Engineering and Systems Analysis Company (GESAC) and Applied Safety Technology Corporation (ASTC) under a contract entrusted by the National Highway Traffic Safety Administration (NHTSA) of the US Department of Transportation. The evaluation tests have been conducted by Japan Automobile Research Institute (JARI) with the financial aid provided by Japan Automobile Manufacturers Association (JAMA).

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