Construction and Evaluation of Scaled Korean Side Impact Dummies

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It is necessary to have a dummy that describes the anthropometry of a victim with accuracy. This study presents three scaled side impact dummies constructed for the use of MADYMO. They represent five, fifty and ninety-five percentile Korean males ranged from the age of 25 through 39. Thirty-five anthropometric data were used to scale input files required for MADYSCALE. Geometries, inertia, joints and other parameters for dummies were scaled based on the configurations of EuroSID-1. This study proposes the lateral impact response requirements for head, thorax and pelvis of Korean side impact dummies. A lateral drop impact test was conducted for the head at the height of 200 mm. Lateral pendulum impact tests were also carried out for thorax and pelvis at three specific impact velocities. All these test results were obtained from simulation based on MADYMO. All the procedures of the three tests followed the requirement of ISO/TR 9790.

Key Words : Side Impact Dummy, Biofidelity, Response Requirement, Anthropometry, MADYMO

Nomenclature

$(R_a)_T$: Thorax acceleration normalizing factor
R_f : Peak force normalizing factor
R_k : Stiffness characteristic ratio
R_m : Mass characteristic ratio
R_t : Time normalizing factor

1. Introduction

Researches in the field of side vehicle crashes should be essential to predicting and reducing the fatal accident results. Impact energy is directly transferred to the passengers in side vehicle crashes, while it is absorbed by the engine booth in frontal crashes. The side impact dummies representing European and American, such as EuroSID-1, US DOT SID and BioSID, have been developed and applied to safety analyses in vehicle crash tests (TNO Automotive, 1999a). Korean side impact dummies, however, have not yet been developed up to now.

Researches have been performed on various anthropometry and dummies. Happee et al. (1998) evaluated dummies with respect to passive safety for a wide range of occupant sizes. The results illustrated that injury parameters exceeded the range of those for the standard dummies due to the different seat positions and occupants weights.

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Harigae et al.(1998) conducted a series of side impact tests to evaluate the biofidelity of the prototype of a small side impact dummy, SID-IIs +. The ISO is in progress to develop a single side impact dummy, WorldSID, with improved biofidelity and worldwide acceptance for both regulatory and research use (Moss et al., 2000).

The researches on human body properties take precedence over the development of dummies. Clauser et al.(1969) and McConville et al.(1980) demonstrated that body size and moment of inertia were related and the correlations could be employed to develop regression equations for predicting mass distribution characteristics. GEBOD (Cheng et al., 1994), GEneration of BOdy Data, was developed to generate body description data using those regression equations for ATB (Obergefell et al., 1988), Articulated Total Body, and the relevant routines from GEBOD have been integrated into the MADYSCALE module of MADYMO, MAthematical DYnamic MOdel (TNO Automotive, 1999b).

For the evaluation of the side impact dummy, the response requirements for lateral impact have been established. ISO/TR 9790 describes the laboratory test procedure and the impact response requirements suitable for assessing lateral impact biofidelity of the crash test dummies. The impact response requirements are organized based on the results of a critical data evaluation, which is collected from the reliable experiments.

Some researches in the field of Korean impact dummies have been achieved. For instance, Jeong (1999) scaled the Hybrid III dummy for Korean average size, and attempted the occupant analysis for Koreans using MADYMO. The experiment results based on the scaled Korean dummy were compared with those of Hybrid III dummy. The various injury trends were also formulated. Park et al.(1999a, 1999b) investigated anthropometric and kinetic characteristics of Korean ranged from the age of 7 through 49. The 14 body segments were considered as components of a human body. For each segment, dimension, volume, density, mass, and center of mass were investigated by employing a Martin-type anthropometer and the immersion method.

In this study, three scaled side impact dummies were constructed and analysed using MADYMO to propose the lateral impact response requirements for head, thorax and pelvis of Korean dummies following the requirements of ISO/TR 9790.

2. Introduction of ISO/TR 9790

ISO/TR 9790 describes the laboratory test procedures and the impact response requirements suitable for assessing the lateral impact biofidelity of the segments. The suggested standard regulates head, neck, shoulder, thorax, abdomen and pelvis of crash test dummies as well as subcomponent test devices. Also it contains mathematical models to represent a 50 percentile adult male. The impact response requirements are organized based on tests such as pendulum, lateral drop and sled tests. The original descriptions are arranged in annex A~R. Table 1 lists various requirements for body segments. The table shows their corresponding clause number in documentation of

Table 1 Test descriptions of ISO/TR 9790

Biofidelity test	Brief test description	Annex
Head 1	200 mm Rigid Drop	E
Head 2	1200 mm Padded Drop	F
Neck 1	7.2 G Sled Test	K
Neck 2	6.7 G Sled Test	L
Neck 3	12.2 G Sled Test	M
Shoulder 1	Pendulum Impact at 4.5 m/s	A
Shoulder 2, 3	7.2 G Sled Test	K
Shoulder 4	WSU Type Sled Test	P
Thorax 1, 2	Pendulum Impact at 4.3 and 6.7 m/s	B, C
Thorax 3, 4	1 m Rigid and 2 m Padded Drops	G
Thorax 5	Heidelberg Type Sled Tests	N
Thorax 6	WSU Type Sled Tests	P
Abdomen 1, 2	1 and 2 m Drops onto Rigid Armrest	J
Abdomen 3~5	WSU Type Sled Test	Q
Pelvis 1, 2	Pendulum Impacts Between 6 and 10 m/s	D
Pelvis 3~6	0.5 and 1 m Rigid & 2 and 3 Padded Drops	H
Pelvis 7~9	Heidelberg Sled Tests	O
Pelvis 10~13	WSU Type Sled Tests	R

ISO/TR 9790 that describes each requirement and identifies the annex and test description.

Base on the these requirements, the scaled Korean side impact dummies were evaluated through completing three tests : the thorax pendulum test in annex B, the pelvis pendulum test in annex D and the lateral head drop test in annex E. The test processes were selected and implemented into modeling and simulating in MADYMO.

The original data in annex B has been collected from the thorax lateral impact tests accomplished by the HSRI, Highway Safety Research Institute (Eppinger et al., 1978). Annex B describes the thorax pendulum test procedures. A rigid cylinder of 23 kg mass and 150 mm diameter with a flat impact face is used. The dummy is seated upright and with its arms raised in order to effectively impact the side of its thorax. The face of the impactor is centered vertically on the lateral aspect of the thoracic rib structure. The impactor having velocity of 4.3 m/s as provided by the description impacts the dummy thorax laterally. The original impact force and lateral acceleration of T1 are normalized by employing an extension of the method described by Mertz (1984). The normalized thoracic acceleration corresponding to time must lie within the corridor described in annex B.

Researchers of ONSERT have contributed to organizing the original data in annex D. For that purpose, 22 unembalmed cadavers were used in the lateral impacts delivered to the greater trochanter (Cesari et al., 1980, 1982, 1983). Annex D contains the pelvis pendulum test procedures. A rigid spherical segment of 17.3 kg mass and 175 mm radius is required as an impactor. The dummy should be seated upright, and the greater trochanter region is impacted at a velocity between 6 and 10 m/s. The peak impact force must lie within the corridor described in annex D.

The original data in annex E is organized based on the results of a series of non-fracture and cadaver head impact tests conducted by Hodgson and Thomas (1975). Annex E describes the head lateral drop test procedures. The flat and rigid horizontal surface and the quick-release mechanism are required as an impactor. Only the dummy head is involved in the test and the head is positioned at 200 mm distance from the impact surface. The appropriate orientation of the head is to have an angle of 35° between its midsagittal plane and the impact surface. Additionally, its anterior-posterior axis should be horizontal. The response requirement addresses the peak resultant head acceleration of a point on the non-impacted side of the head. The peak resultant head acceleration must lie within the bounds from 100 to 150 G.

3. Scaled Korean Side Impact Dummies

This study utilized a national anthropometric survey (KRISS, 1997) to construct the scaled Korean side impact dummies. This report has surveyed Koreans ranged from the age of 0 to 70, and contains the basic statistical data of body dimensions, such as height, breadth and distance between anatomical points.

The scaling method was developed to generate models of subjects with varying anthropometry. Typically, the scaling process requires the parameterized description of the anthropometry of the reference dummy model. This model was of scaled one with the same structure (bodies, ellipsoids, force models) as the reference model, as well as with the specified anthropometry. MADYMO contains EuroSID-1 as the reference model to be used as the side impact dummies. The scaling process here was accomplished with MADYSCALE module (TNO Automotive, 1999b).

The desired anthropometry can be specified in a convenient way using GEBOD. This requires only the mass and/or body standing height (and/or age for children). The relevant routines contained in GEBOD were integrated into the MADYSCALE module, and these were used to generate a set of 35 anthropometric parameters as listed in Table 2. Alternatively, these 35 parameters can be decided by users. This set of parameters can be generated with GEBOD and then edited to describe a specific subject. The latter was applied to Korean side impact dummies.

A more advanced scaling method contained in

MADYSCALE specified the different scaling factors with respect to x, y and z directions. Furthermore, the different scaling factors were applied to different body parts. All scales were determined based on the desired anthropometric parameters, such as geometry, masses, moments of inertia, joint models and characteristics, ellipsoids, contact characteristics and all other force models.

Table 2 Anthropometry parameters required for scaling

No	Parameter	No	Parameter
1	Weight	19	Forearm-hand length
2	Standing height	20	Biceps circumference
3	Shoulder height	21	Elbow circumference
4	Armpit height	22	Forearm circumference
5	Waist height	23	Wrist circumference
6	Seated height	24	Knee height, seated
7	Head length	25	Thigh circumference
8	Head breadth	26	Upper leg circumference
9	Head to chin height	27	Knee circumference
10	Neck circumference	28	Calf circumference
11	Shoulder breadth	29	Ankle circumference
12	Chest depth	30	Ankle height, outside
13	Chest breadth	31	Foot breadth
14	Waist depth	32	Foot breadth
15	Waist breadth	33	Hand breadth
16	Buttock depth	34	Hand length
17	Hip breadth, standing	35	Hand depth
18	Shoulder to elbow length		

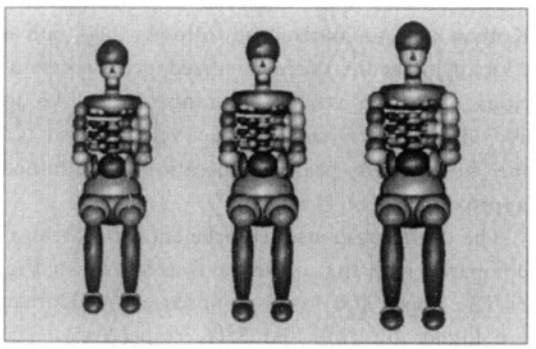

Fig. 1 Korean side impact dummies (five, fifty and ninety-five percentiles)

Three scaled Korean side impact dummies were constructed using MADYMO version 5.41. Mathematical EuroSID-1 provided a rigid and a flexible body database in MADYMO. The rigid body database was employed to scale the Korean side impact dummies. They represent five, fifty and ninety-five percentile Korean ranged from the age of 25 through 39. The values of thirty-five anthropometric parameter were scaled and prepared to the scaling input files for MADYSCALE. The five, fifty and ninety-five percentile Korean side impact dummies were developed and are shown in Fig. 1.

4. Evaluation of Korean Side Impact Dummies

4.1 Thorax pendulum impact test

The thorax pendulum impact test followed the procedure described in ISO/TR 9790. The Korean side impact dummies were seated upright and with their arms raised. The cylinder impacted the thorax at a regulated velocity of 4.3 m/s. The lateral accelerations of T1 were filtered at FIR 100. Figure 2 illustrates the thorax pendulum impact test with intervals of 10 ms. This test simulation was carried out with a 50 percentile Korean side impact dummy in MADYMO.

Figure 3 shows the T1 accelerations of five, fifty and ninety-five percentile Korean side impact dummies. Their peak accelerations reached 19.3, 16.3 and 14.1 G, respectively. These accelerations were attained at 11.8, 10.3 and 11.0 ms after contacting the pendulum and thorax. From these results, if the other dummy characteristics are identical, the weight of dummy positively affects the peak acceleration of T1. The lateral peak accelerations of T1 were normalized and the calculated characteristic ratios and normalizing factors are listed in Table 3. The mass ratio, R_m, and the thoracic stiffness ratio, R_k, are defined as :

$$R_m = M_s / M_c \tag{1}$$

$$R_k = K_s / K_c \tag{2}$$

where M represents the thoracic mass ; subscript

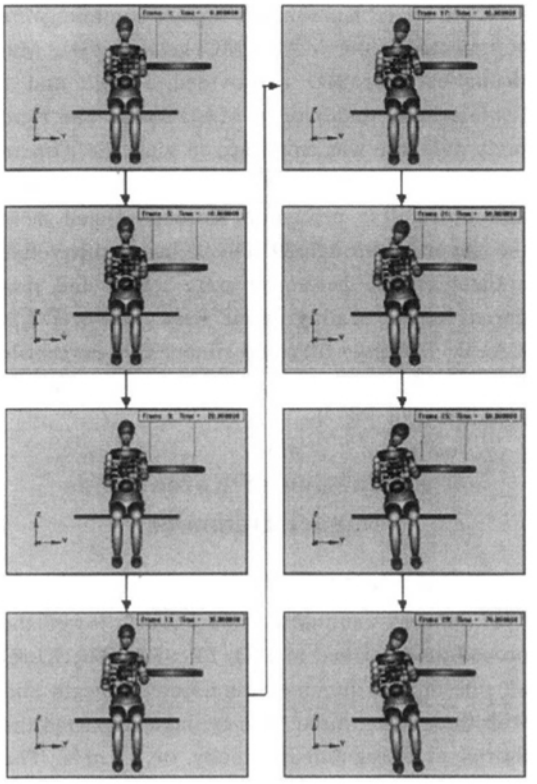

Fig. 2 Thoracic impact test for the 50 percentile Korean side impact dummy

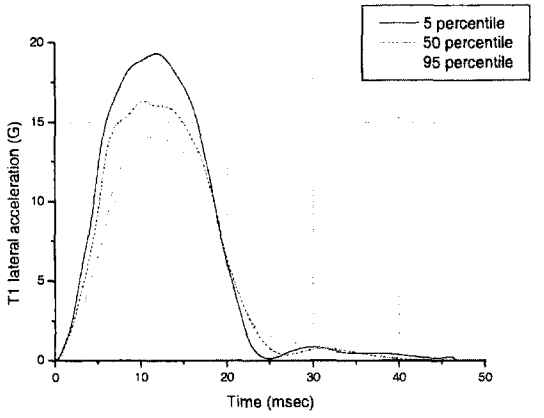

Fig. 3 Thoracic test results for the Korean side impact dummies

k the thoracic stiffness ; subscript s the standard subject ; and subscript c the cadaver.

For the five, fifty and ninety-five percentile Koran side impact dummies, the normalized peak accelerations of T1 were in the range of 14.6 to 16.7 G. The accelerations were attained at 10.2 to 11.8 ms after the pendulum and thorax were contacted. Figure 4 illustrates the normalized lateral acceleration of T1 corresponding to time and the response requirement for thorax. These results assess the biofidelity of Korean side impact dummies. The response requirements for Korean are summarized as follows : (1) with a 23.4 kg impactor, the normalized peak accelerations of T1 lie within the range from 14.6 to 16.7 G at 4.3 m/s lateral impact velocity, and (2) the normalized peak acceleration is attained approximately at 11 ms.

The thorax response requirement for Korean is compared with that of annex B as shown in Fig. 5. The upper and lower boundaries for Korean are higher by 11% and 83%, respectively. The peak acceleration of Korean occurs about 4 ms earlier than that of annex B.

Table 3 Thoracic normalizing factors of the Korean side impact dummies

Korean human male	Characteristic ratio		Hormalizing factor	
	Mass R_m	Sitffness R_k	Thorax acceleration $(R_a)_T$	Time R_t
5%ile	1.382	1.191	0.866	1.005
50%ile	1.125	1.071	0.950	0.998
95%ile	0.921	0.961	1.042	0.998

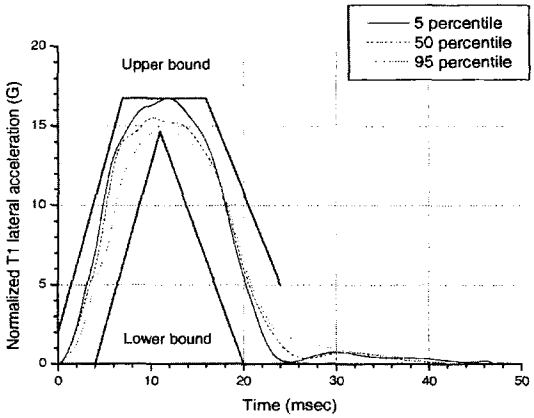

Fig. 4 Thoracic response requirements for Korean

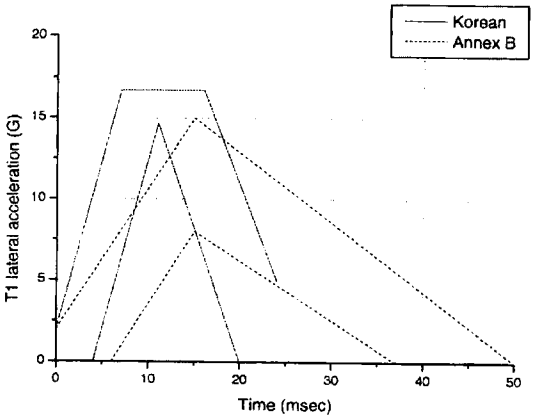

Fig. 5 Comparison of responses for Korean and annex B

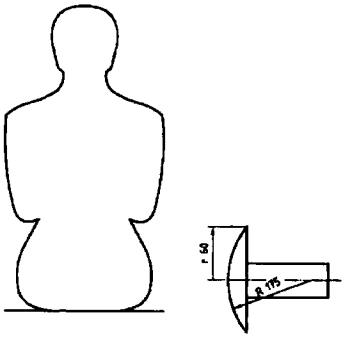

Fig. 6 Test configuration for pelvis test

4.2 Pelvis pendulum impact test

The pelvis pendulum impact test was accomplished by following the procedure described in ISO/TR 9790. As the test set up, the Korean side impact dummies were seated upright without raising their arms. The rigid pendulum with a spherical segment impact face was used as illustrated in Fig. 6. The pelvis was impacted laterally at velocities of 6, 7 and 8 m/s. Figure 7 illustrates the pelvis pendulum impact test with intervals of 10 ms, which was simulated with a 50 percentile Korean side impact dummy.

Figure 8 shows the impactor forces of five, fifty and ninety-five percentile Korean side impact dummies tests. The peak impactor force as a function of impact velocity was higher in the heavier (95%ile) than the lighter weight (5%ile). The peak impactor forces were also normalized and the calculated characteristic ratios and normalizing factors are listed in Table 4.

Table 4 Pelvic normalizing factors of Korean side impact dummies

Korean human male	Characteristic ratio		Normalizing factor
	Mass R_m	Stiffness R_k	Peak force R_f
5%ile	1.382	1.070	1.216
50%ile	1.126	1.019	1.071
95%ile	0.921	1.071	0.974

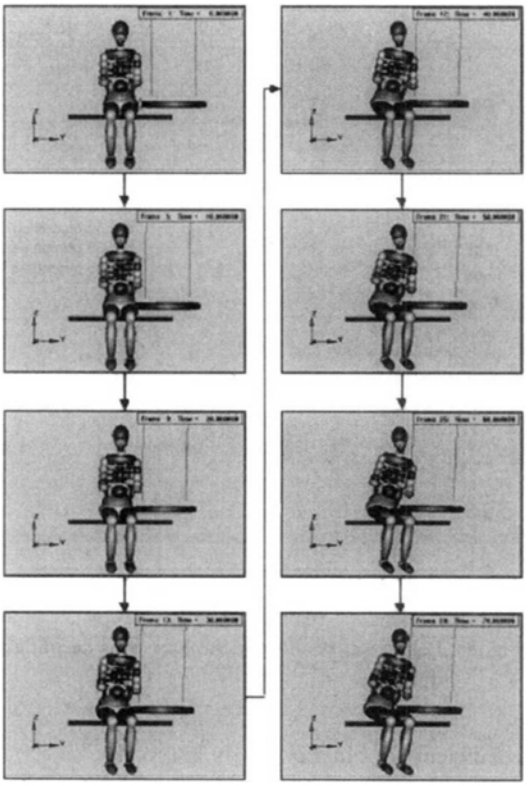

Fig. 7 Pelvic impact test for the 50 percentile Korean side impact dummy

Table 5 shows the normalized pelvis test results of five, fifty and ninety-five percentile Koran side impact dummies corresponding to the impact velocities of 6, 7 and 8 m/s. A linear regression equation is obtained as

$$F = -2.82 + 1.33\ V \qquad (3)$$

where F is the normalized peak force and V is impact velocity. This linear regression is valid only for $6\ \text{m/s} \leq V \leq 8\ \text{m/s}$. The unit of the

Table 5 Pelvic test results for the Korean side impact dummies

Korean human male	Impact velocity (m/s)	Peak force (kN)	Normalized peak force (kN)
5%ile	5.99	4.24	5.16
	6.99	5.37	6.53
	7.99	6.44	7.83
50%ile	5.99	4.68	5.01
	7.00	5.84	6.26
	8.00	6.97	7.46
95%ile	5.98	5.07	4.94
	6.97	6.27	6.11
	7.97	7.43	7.24

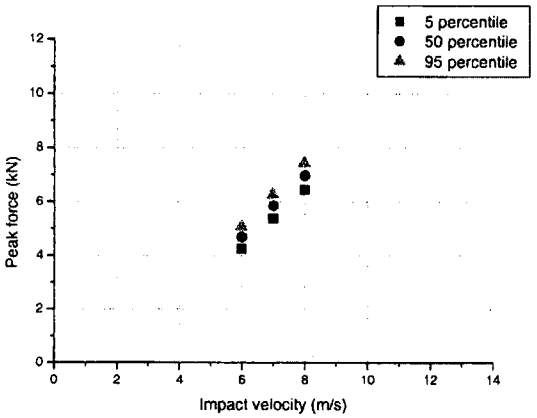

Fig. 8 Pelvic test results for the Korean side impact dummies

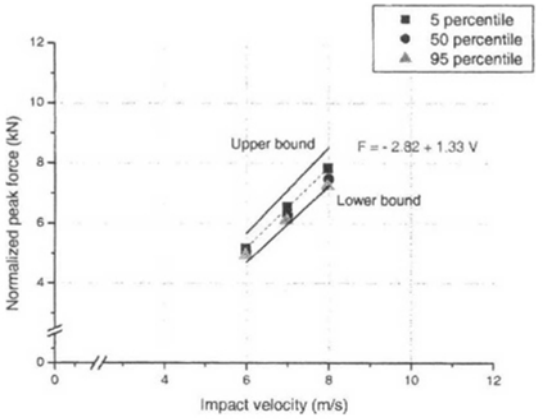

Fig. 9 Pelvic response requirements for Korean

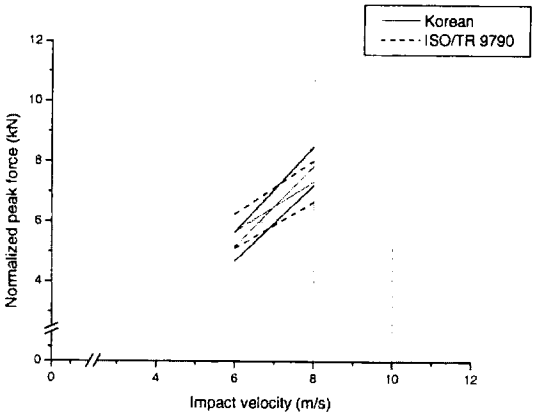

Fig. 10 Comparison of responses for Korean and annex D

coefficient 1.33 in Eq. (3) is kN·s/m.

The normalized peak force versus impact velocity and the response requirement for pelvis is proposed as shown in Fig. 9 to assess the biofidelity of Korean side impact dummies. The response requirements for Korean are determined as follows: (1) for dummy impacts at velocities of 6 and 8 m/s with the 17.3 kg rigid impactor, the relationship between the normalized peak impactor force and impact velocity is represented in Eq. (3), and (2) the response corridor is within the range of ±6% slope in Eq. (3).

The pelvic response requirement for Koreans is compared with that of annex D as shown in Fig. 10. The normalized peak forces at an impact velocity of 7 m/s are found to be almost the same for both the Korean and ISO/TR 9790. But the regression equation for Koreans is steeper by 60%. Therefore, the peak impactor forces are lower at velocities of 6 to 7 m/s and higher at 7 to 8 m/s than ISO/TR 9790.

4.3 Lateral head drop test

The lateral head drop test was conducted with only the dummy head. The head was positioned at 200 mm distance from the impact surface. The proper orientation of a head was determined as suggested in ISO/TR 9790, and also its anterior-posterior axis was fitted. The peak resultant head acceleration and the impact velocity were measured on the non-impacted side of the head. Figure 11 illustrates the lateral head drop test with

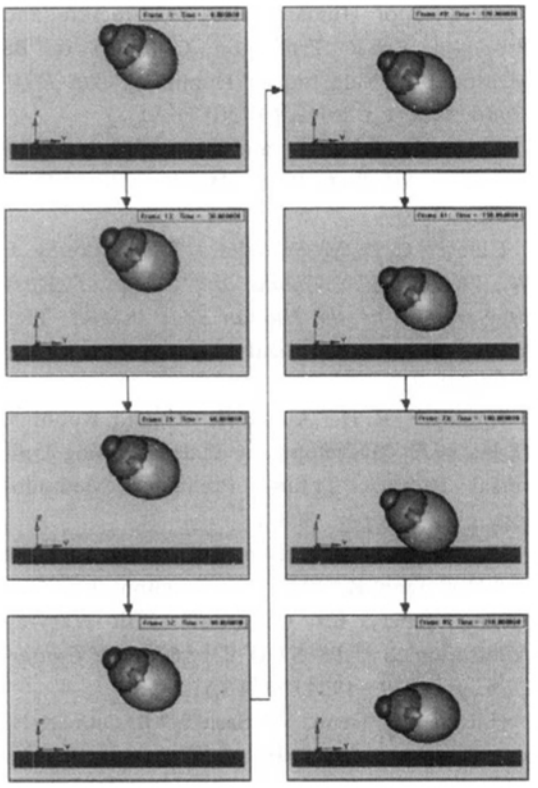

Fig. 11 Head impact test for the 50 percentile Korean side impact dummy

intervals of 30 ms, which was simulated for a 50 percentile Korean side impact dummy using MADYMO.

The test results for Korean are summarized in Table 6. The head impact velocities were approximately within the range of 1.75~1.80 m/s. The peak resultant head acceleration attained the range of 125~148 G. From this result, From this result, the peak resultant head acceleration is higher than the case when the head mass is lighter while other head characteristics remain the same.

The response requirement for head is summarized as shown in Fig. 12 to assess the biofidelity of Korean side impact dummies. The response requirements for Korean are determined as follows : (1) the peak resultant head acceleration is within the range of 140~165 G in the case of 200 mm head drop test with head angel of 35°, and (2) the impact velocity lies approximately within the range of 1.75~1.80 m/s.

Table 6 Head test results for the Korean side impact dummies

Korean human male	Impact velocity (m/s)	Peak resultant head acceleration (G)
5%ile	1.80	148
50%ile	1.78	136
95%ile	1.75	125

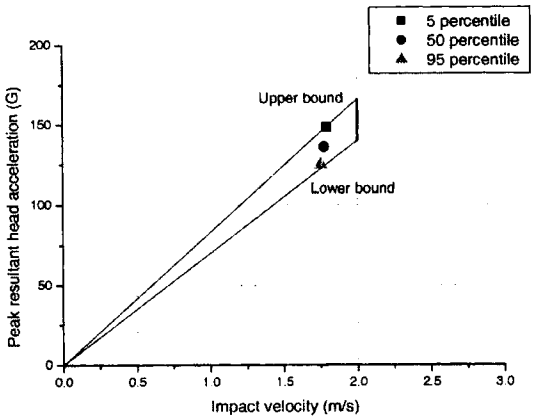

Fig. 12 Head response requirements for Korean

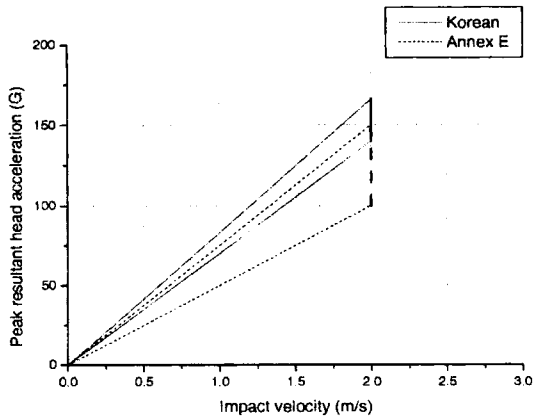

Fig. 13 Comparison of responses for Korean and annex E Tables and Figures

The head response requirement for Korean is compared with that of annex E as shown in Fig. 13. The upper and lower boundaries for Korean are higher by 10% and 40%, respectively. The boundary width for Korean is narrower up to 50%.

5. Conclusion

This paper constructed Korean side impact dummies in order to predict the lateral impact response requirements for head, thorax and pelvis of Koreans. Thirty-five Korean anthropometric data were utilized for the scaling process, and three male dummies aged from 25 to 39 were also constructed. The lateral drop and pendulum impact tests were completed on the head, thorax and pelvis using MADYMO.

According to the results of tests and comparisons with ISO/TR 9790, the thorax response requirement for Koreans reveals that the upper and lower boundaries are higher by 11% and 83%, respectively. The peak acceleration of Koreans occurs about 4 ms earlier than that of the standard. In the pelvic response requirement, the slope of the regression equation for Koreans is higher by 60%, and the peak impactor force increases as the impact velocity does. For the head response requirement for Koreans, the upper and lower boundaries are higher by 10% and 40%, respectively. The boundary width for Koreans is narrower up to 50%.

The response requirements for the scaled Korean dummies are different from those of ISO/TR 9790. Due to the different anthropometric data, the response of dummies exceeds the range of results for the standard response requirement. However, the subjects for Korean were restricted to male within specific ages in this paper. To establish more reliable dummy response requirements, it is recommended to obtain test results adapted cadavers as well as various Korean anthropometric data.

References

Cesari, D., Ramet, M. and Clair, P., 1980, "Evaluation of Pelvic Fracture Tolerance in Side Impact," *SAE* Paper 801306.

Cesari, D. and Ramet, M., 1982, "Pelvic Tolerance and Protection Criteria in Side Impact," *SAE* Paper 821159.

Cesari, D., Ramet, M. and Bouquet, R., 1983, "Tolerance of Human Pelvis to Fracture and Proposed Pelvic Protection Criterion to Be Measured on Side Impact Dummies," *9th ESV Conference*, pp. 261~269, NHTSA.

Cheng, H., Rizer, A. and Obergefell, L., 1994, *Generator of Body Data Manual, Springfield*, NTIS.

Clauser, C. E., McConville, J. T. and Young, J. W., 1969, *Weight, Volume and Center of Mass of Segments of the Human Body*, AMRL-TR-69-70, Aerospace Medical Research Laboratory, WPAFB OH.

Eppinger, R. H., Augustyn, K. and Robbins, D. H., 1978, "Development of a Promising Universal Thoracic Trauma Prediction Methodology," *SAE* Paper 780891.

Happee, R., Michaelsen, L., van Haaster, R. and Hoffmann, R., 1998, "Optimizaton of Vehicle Passive Safety for Occupants with Varying Anthropometry," 98-S9-O-03, *16th ESV Conference*, pp. 1919~1924, NHTSA.

Harigae, T., Ueno, M., Sasaki, M., Ohmae, H. and Uchimura, T., 1998, "Performance Evaluation of Impact Responses of the SID-IIs Small Side Impact Dummy," 98-S7-O-02, *16th ESV Conference*, pp. 1532~1541, NHTSA.

Hodgson, V. R. and Thomas, L. M., 1975, "Head Impact Response," *Vehicle Research Institute Report 7.2, SAE*.

ISO, 1999, *ISO/TR 9790: Road Vehicles — Anthropomorphic Side Impact Dummy — Lateral Impact Response Requirements to Assess the Biofidelity of the Dummy*, ISO.

Jeong, Y. H., 1999, "Passenger Safety Analysis Using MADYMO with Scaled Korean Dummy Models," *Master Thesis, Hanyang University*.

KRISS, 1997, *National Anthropometric Survey of Korea*, KRISS-97-114-IR.

McConville, J. T., Churchill, T. D., Kaleps, I., Clauser, C. E. and Cuzzi, J., 1980, *Anthropometric Relationships of Body and Body Segment Moments of Inertia*, AMRL-TR-80-119 (AD A097238), Aerospace Medical Research Laboratory, WPAFB OH.

Mertz, H. J., 1984, "A Procedure for Normalizing Impact Response Data," *SAE* Paper 840884.

Moss, S., Wang, Z., Salloum, M., Reed, M., van Ratingen, M., Cesari, D., Scherer, R., Uchimura, T. and Beusenberg, M., 2000, "Anthropometry for WorldSID : A World-Harmonized Midsize Male Side Impact Crash Dummy," *SAE* Paper 2000-01-2202.

Obergefell, L. A., Gardner, T. R., Kaleps, I. and Fleck, J. T., 1988, *Articulated Total Body Model Enhancements Volume 2 : User's Guide*, Harry G. Armstrong Aerospace Medical Research Laboratories.

Park, S. J., Park, S. C., Kim, J. H. and Kim, C. B., 1999a, "Biomechanical Parameters on Body Segments of Korean Adults," *International Journal of Industrial Ergonomics*, Vol. 23, pp. 23~31.

Park, S. J., Kim, C. B. and Park, S. C., 1999b, "Anthropometric and Biomechanical Characteristics on Body Segments of Koreans," *Journal of Physiological Anthropology*, Vol. 18, No. 3, pp. 91~98.

TNO Automotive, 1999a, *MADYMO Database Manual 3D Version 5.4*, TNO Automotive.

TNO Automotive, 1999b, *MADYMO Utilities Manual 3D Version 5.4*, TNO Automotive.