The Analysis of an Individual Difference in Human Skeletal Alignment in Seated Posture and Occupant Behavior Using HBMs

Tomohiro Izumiyama, Norihiro Nishida, Hideyuki Iwanaga, Xian Chen, Junji Ohgi, Koji Mori, Takafumi Hayashi, Itsuo Sakuramoto, Ryusuke Asahi, Shigeru Sugimoto, Masaki Ueno

Abstract To reduce fatalities or serious injuries, the object of this study was to research skeletal alignment in an automotive seat and clarify the differentiation by the factors of age, gender and body type. Additionally, it was also to create human body models which represent individual differences by morphing the skeletal alignment of THUMS based on the analysis results, and consider the structure of seats to ensure occupant safety by using those human body models. Analysis on X-ray data revealed that the alignment in seated posture is classified into the following two types: mild S-shaped and Kyphosis, and tends to be influenced by body mass index. To analyse the effects on occupant kinematics, especially the region of the abdomen and lumbar, by the difference of skeletal alignment in frontal impact, multiple models were created by morphing the skeletal alignment of THUMS ver.4. Then, the occupant kinematics has been studied by using those HBMs, and the results indicated a significant difference especially in pelvic region. Considering from the aspect of occupant protection in accidents, it shows that it is important to maintain the correct driving position.

Keywords BMI, individual difference, seated posture, skeletal alignment, pelvis

I. INTRODUCTION

In Japan, head and chest represent the most common injury locations in fatal accidents. On the other hand, considering the number of serious injuries of occupants in frontal crashes in Japan, abdominal injuries account for a large portion. In particular, injuries of intestines and mesentery in the lower abdomen are dominant. It is assumed that one of the causes of abdominal injury is lap seatbelts. Automotive manufacturers have been improving the restraint systems such as pre-tensioner with optimised load limiter to keep the occupant in position, and designing seatbelt fittings to the ilium tightly in a regular driving posture (Fig. 1). However, understanding the effect of the individual differences in seated posture is also necessary in order to provide an appropriate driving posture and seatbelt constraint. So far many studies for spinal alignment in standing and seated posture have been reported. For example, the correlation between age and sagittal spinal alignment has been researched by analysing the angles of thoracic kyphosis, lumbar lordosis, sacral inclination and sagittal vertical axis (SVA) in 100 asymptomatic middle-aged and elderly volunteers [1]. Additionally, the variation of skeletal alignment between standing and seated posture has been discussed by the combination of some angles from cervical spine to pelvis [2-4]. The spinal alignment of THUMS pedestrian model has been also compared to the skeletal model of two male subjects [5]. Moreover, the influence of skeletal alignment in different some seated postures by a three dimensional digitizing system and the difference of whole skeletal alignment in seated posture using MRI systems have been reported [6-8]. However, there are few studies which analyse the skeletal alignment of subjects in a wide range of ages and body sizes in seated posture using an actual automotive seat.

This study aimed to (a) analyse the individual differences in human skeletal alignment depending on age, gender, and body size, (b) incorporate the results into human body models (HBMs), and (c) using these models, clarify the influence of skeletal alignment on the pelvic kinematics by crash simulations.

Tomohiro Izumiyama (Tel: +81-82-565-1189, E-mail: izumiyama.t@mazda.co.jp) and Ryusuke Asahi are Engineers, Shigeru Sugimoto is a Manager, Crash Safety Technology Development Group and Masaki Ueno is General Manager, Crash Safety Development Dept., all at Vehicle Development Div., Mazda Motor Corporation, Japan. Norihiro Nishida is Assistant Professor, Department of Orthopedic Surgery, Yamaguchi University Graduate School of Medicine, Japan. Hideyuki Iwanaga is Associate-Chief Radiological Technologist, Department of Radiological Technology, Yamaguchi University Hospital. Xian Chen is Professor, Junji Ohgi and Koji Mori is Associate Professor in the Department of Mechanical Engineering at Yamaguchi University. Takafumi Hayashi is a Graduate Student, Applied Medical Engineering Science, Graduate School of Medicine, Yamaguchi University. Itsuo Sakuramoto is Professor, Department of Mechanical and Electrical Engineering at National Institute of Technology, Tokuyama College, Japan.

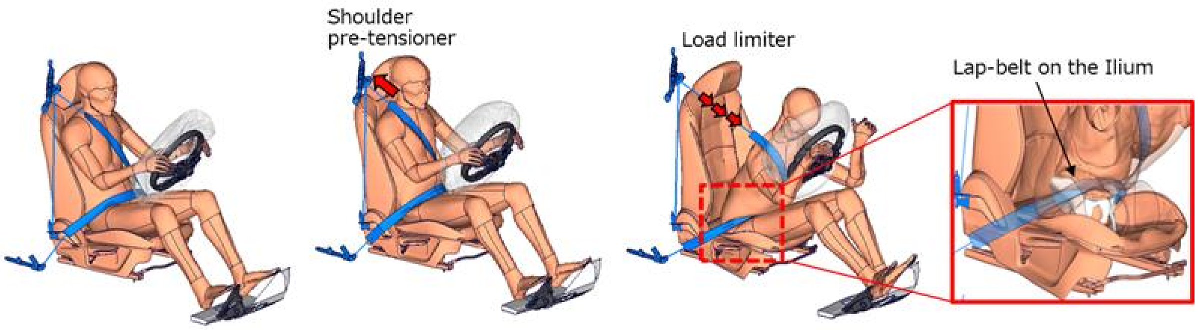


Fig. 1. The seatbelt kinematics on HBM in the frontal impact.

II. METHODS

Fabrication of an X-ray Facility with an Actual Automotive Seat and Posture Definition

In order to reproduce the posture seated in an automotive driver seat, an original device equipped with a seat of a Mazda3 (MY2013-2016) has been fabricated (Fig. 2a). Those devices were placed on a table, 1,200 mm in length, 600 mm in width, and 500 mm in height. The structure was so designed that the seat can be replaced. The subjects with light clothing were X-rayed while seated in the automotive seat as well as in a standing posture (Fig. 2b, c). The automotive seat was set with its seat back inclined 24 degrees and seat pan inclined 21.5 degrees. The seat was installed with its sliding functions so that each subject can adopt an appropriate driving posture. The subjects were asked to sit back with their foot on the pedal and footrest, both arms on the arm rest while being X-rayed, and the usual driving posture. The location of subjects was adjusted to keep their center lines in parallel with the X-ray table so as to achieve a pure lateral X-raying.

(a)The automotive seat facility (b)Seated posture (c)Standing posture

Fig. 2. The X-ray facility and situations of X-raying.

Subjects

75 asymptomatic subjects without any medical history in the vertebral body or pelvis, who gave informed consent after explanation of the overview of the study, were subjected to X-ray photography. The subjects are divided into groups: for age, (1) 20 to 39 years, (2) 40 to 59 years, and (3) 60 years or older; for height, (4) less than 155 cm, (5) 155 cm to 170 cm, exclusive, and (6) 170 cm or more; and for body mass index (BMI), (7) less than 22, (8) 22 to 30, exclusive, and (9) 30 or more.

X-raying and Procedures in this Study

In this study, X-ray images were taken using the SONIALVISION Safire17 SHIMADZU, a multi-functional universal R/F system at Department of Radiological Technology, Yamaguchi University Hospital. All X-ray data were scanned and output by the X-ray TV system of the Radiology Department of Yamaguchi University Hospital. Subjects' bodies were scanned in the order of legs, pelvis, lumbar spine, thoracic spine, cervical spine, and head. The scanning range covered from the pelvis to neck in the inferior-superior direction and from the femur to the rearmost vertebral body in the anterior-posterior direction. All procedures in this study were determined by

Yamaguchi University and Mazda Motor Corporation and approved by the ethical committees of both Yamaguchi University Graduate of Medicine and Mazda Motor Corporation.

X-ray Data Analysis

For the measurement of spinal alignment and pelvis angle, seven parameters were used. Out of them, four parameters were for vertebral body: one for cervical spine, two for thoracic spine, and one for lumbar spine. The angle between the line passing through the top plane of the upper vertebral body and one passing through the bottom plane of the lower vertebral body was measured. The remaining three parameters were measured for the pelvis. Sacral slope was measured by the angle between the line passing through the top plane of sacrum and the horizontal line. Generally the sacral slope can be used for representing the pelvic angle. However, in order to remove the individual variation of the sacroiliac joint, the angle between the line passing through the pubic symphysis and anterior-superior iliac spine (ASIS) relative to a vertical line was also measured directly as the pelvic angle. In addition, as the pelvis width, the distance between the end of right ilium and that of the left ilium was measured in the skeletal data in a standing posture. The details are provided below (Fig. 3):

(1) Cervical curvature (CC): angle between C2 and C7 [9]
(2) Thoracic kyphosis (TK): angle between T5 and T12 [9]
(3) Thoracolumbar kyphosis (TLK): angle between T10 and L2 [10]
(4) Lumbar lordosis (LL): angle between L1 and L5 [9, 11]
(5) Sacral slope (SS): angle between sacrum and the horizontal line [9, 11]
(6) Pelvic angle (PA): pubic symphysis to ASIS [12]
(7) Width of pelvis: length between end of left and right ilium

For the spinal angles, the positive and negative values indicate lordosis and kyphosis, respectively. For the pelvic tilt, the positive values indicate anterior tilt of the sacrum and pelvis, whereas the negative values indicate posterior tilt of them. Anterior tilt was defined as the sacrum top plane is below the horizon or the line of pubic to ASIS lies anterior to a vertical line, and vice versa.

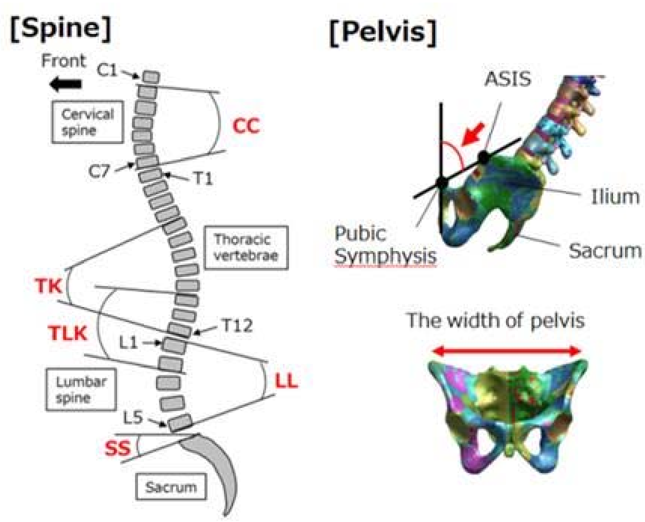


Fig. 3. Measurement items for spine and pelvis.

Using the data of angle measurement (CC, TK, TLK, LL, SS, and PA), the skeletal alignments were classified. Next, the variability range of each angle was investigated. For each angle (CC through PA), the normal distribution was drawn by gender and the coefficient of variation was calculated by dividing the standard deviation by the average value. In this study, lumbar spine and pelvis were particularly focused on so as to clarify the difference in pelvis kinematics. Therefore, the variability of LL and PA by gender, age, height and BMI were analysed in detail.

Creation of FE-HBMs

The pelvic angle (PA) was focused on in this study to create different types of HBM used for the analysis on the pelvic kinematics. A normal distribution curve was applied to the data obtained from x-ray in order to statistically infer the population. Next, representative pelvic angles of 50th percentile, 10th percentile, and 1th

percentile were selected from the distribution. Referring to the angles of the lumbar spine, sacrum, and pelvis of subjects whose pelvic angle is close to respective representative angles, the skeletal alignment of THUMS ver.4 AM50 was modified by giving a Prescribed-Motion on the vertebrae of the thorax spine, lumbar spine, and pelvis. Femur joint was allowed to rotate but not translate. The hands, lower extremities, and cervical vertebrae were completely constrained.

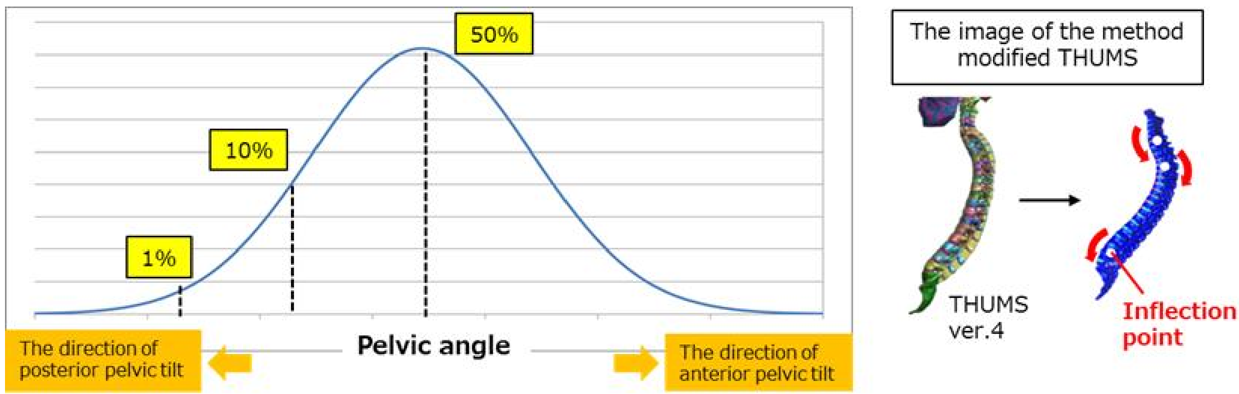
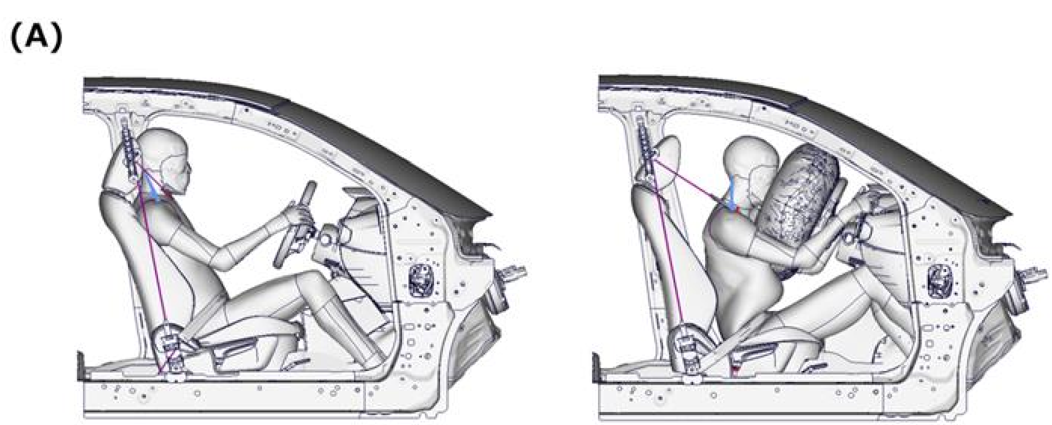
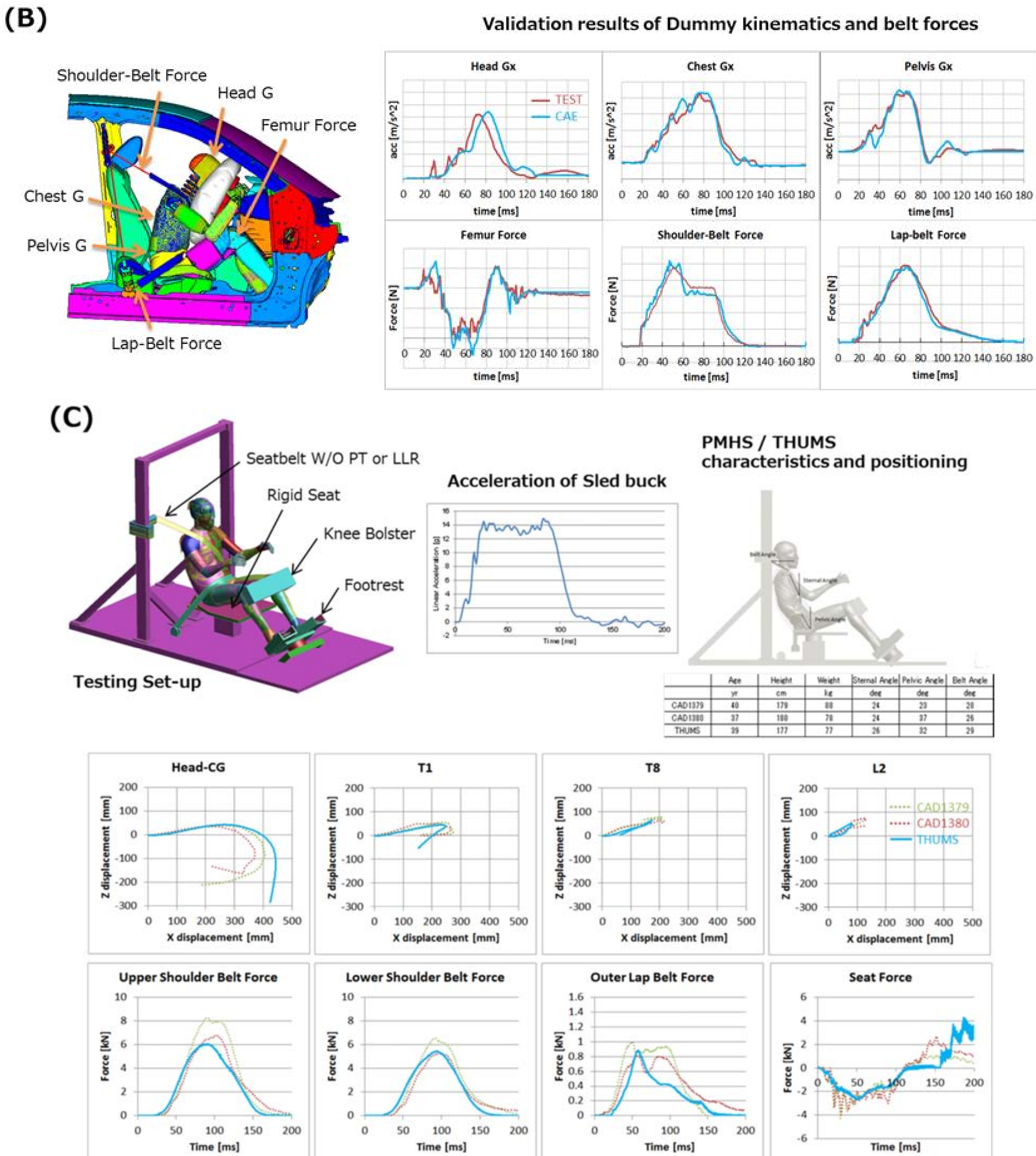


Fig. 4. Normal distribution of pelvic angle and the method to modify the skeletal alignment of THUMS.

Condition of FE Simulation

In this study, simulations were conducted with the same condition of JNCAP 56kph full lap frontal impact (Fig. 5(A)). Car models included in simulation were based on Mazda's typical specification and the 6 DOF accelerations were applied to the car body about its CG in order to simulate the vehicle kinematics. The validation results of simulation model with the Hybrid III AM50 dummy were shown in Fig. 5(B). The similar dummy kinematics and seatbelt forces in CAE simulation were confirmed by comparison to that in sled test. Besides, the validation results of THUMS ver.4 with NHTSA PMHS tests (Report#: b11015R001) were shown in Fig. 5(C). The graphs indicated that the kinematics of THUMS model was almost the same as that of PMHS. Using THUMS AM50 with modified PA for 50th percentile (PA50), 10th percentile (PA10), and 1th percentile (PA01), their kinematics in frontal crashes was investigated. Those models were placed in the driver seat and constrained by a seatbelt with pre-tensioner and load limiting retractor. THUMS was positioned with hands on the wheel, while feet on the accelerator pedal and footrest as well as the Hybrid III AM50 dummy. Positions and angles of pelvis, spine and head depend on the corresponding alignment. Shoulder Seatbelt and lap seatbelt were fit on the chest and pelvis, respectively. Seat cushion was squashed in order to consider the initial compression by the gravity.





	Age	Height	Weight	Sternal Angle	Pelvic Angle	Belt Angle
	yr	cm	kg	deg	deg	deg
CAD1379	40	179	88	24	23	28
CAD1380	37	180	78	24	37	26
THUMS	39	177	77	26	32	29

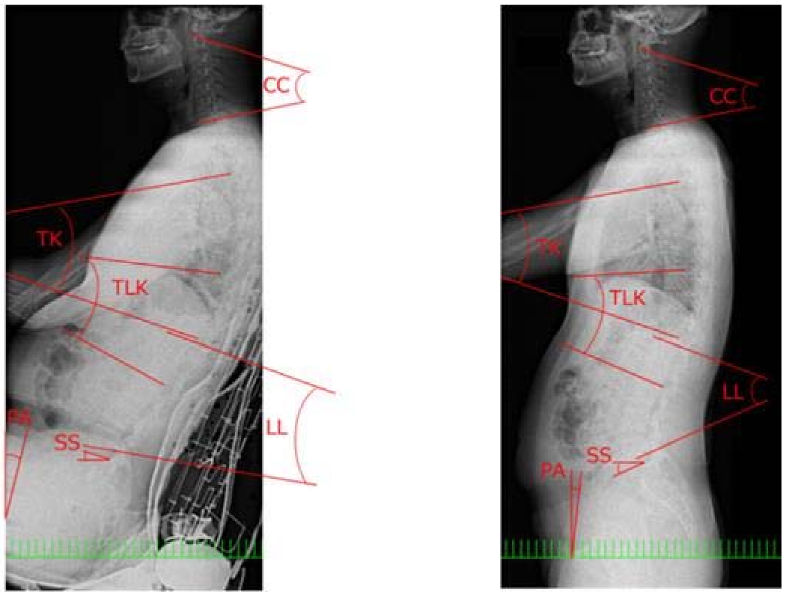
Fig. 5. The FE simulation model (A) and the kinematics validation results of vehicle model (B) and THUMS model (C).

Analysis of Injury Measures

Using the results of FE simulations, injury measures to the head, neck, chest, pelvis and femur were conducted. For the head, HIC was calculated from the head translational accelerations. For the neck, the axial compression loads at Z-axis and moments around Y-axis at C2 were calculated. For the chest, deformation related to the spine at the upper (equivalent to rib2), middle (equivalent to rib4) and lower (equivalent to rib7) location of the sternum was measured. For the pelvis, the displacement of H-point, rotation around the y-axis, and the lap seatbelt sliding-up movement were measured. For the femur, the axial force on the middle of the femur shaft was calculated.

III. RESULTS

Totally 75 subjects have been x-rayed and the details of subjects are provided in Appendix Table 1-2. A sample of X-ray image is shown in Fig. 6.



(a)Seated posture (b)Standing posture

Fig. 6. X-ray images of seated and standing postures with each angle for the spine and pelvis.

The data of skeletal alignment in seated posture obtained from 75 subjects were analysed and classified into the following two types in terms of lumbar lordosis (LL): those who had an S-shaped alignment with lumbar lordosis, and others who showed kyphosis from the thoracic spine all the way through the lumbar spine (Fig. 7). Normal distribution curves of each angle in seated posture were shown in Fig. 8. Though the coefficient of variation of LL was the largest in relative comparison, large variability could be observed for both LL and PA in terms of the standard deviation. Neither LL nor PA showed strong correlation to the human factors such as age, height and BMI (Fig. 9). PA of males with higher BMI (more than 30), however, fell within the range from -32 deg. to -43 deg., although PA of males with lower BMI distributed over a wide range from -28 deg. to -62 deg. (see the red frame in Fig. 9).

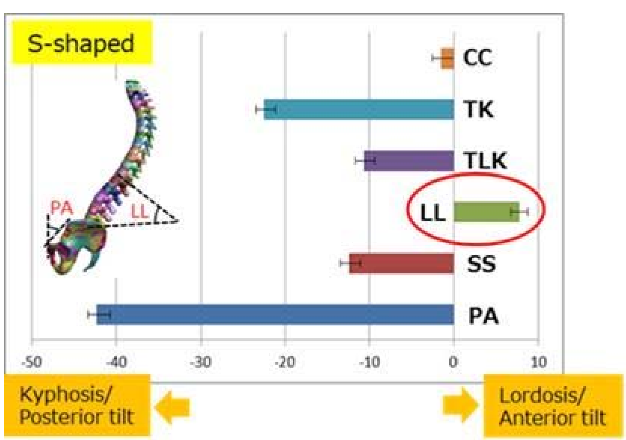


Fig. 7. Two types of skeletal alignment in seated posture (average values).

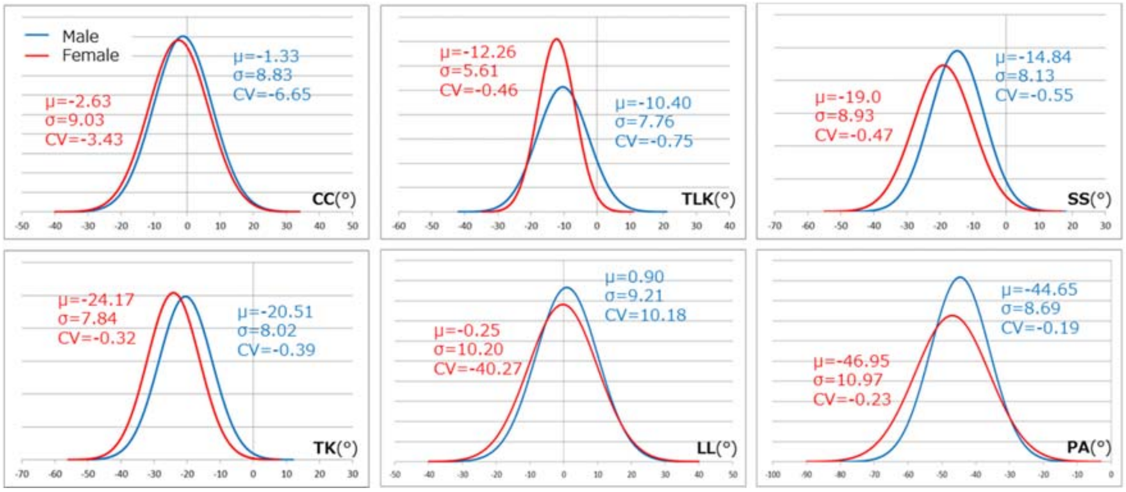


Fig. 8. Normal distribution and variation of each angle in seated posture.

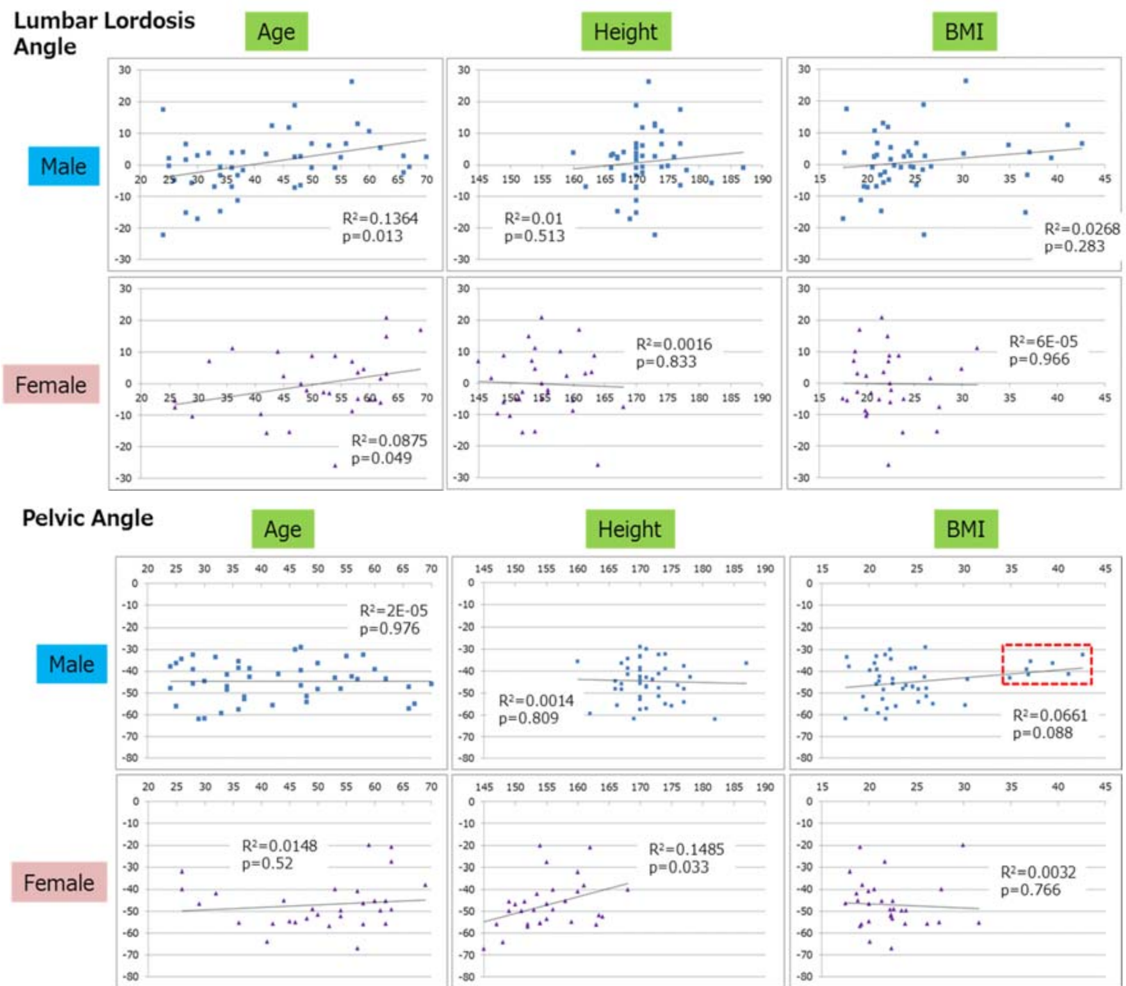


Fig. 9. Analysis on the angle of the lumbar spine and pelvis for 75 subjects by gender.

To confirm the hypothesis that this tendency depends on the skeletal alignment in standing posture, the comparison of skeletal alignment between standing and seated postures was investigated from the perspectives of BMI. Looking at the average of subjects whose BMI was more than 30, we found that there is a big difference in skeletal alignment of standing posture between those with S-shaped alignment and others with kyphosis in seated posture. The former shows significantly wide S-shape in standing posture (Fig. 10).

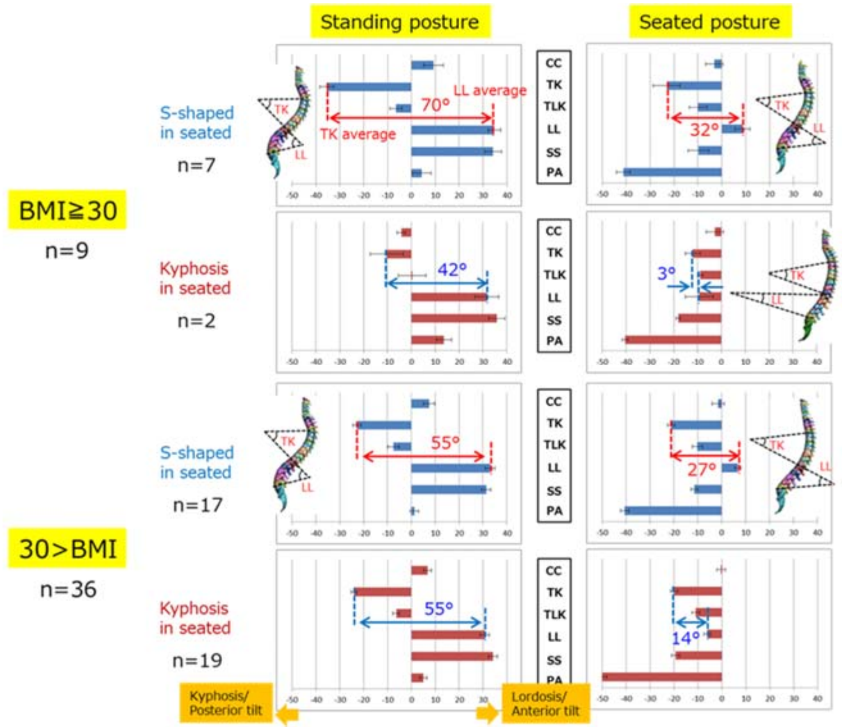


Fig. 10. The change of male skeletal alignment between standing and seated posture by BMI.

Based on the measurement data, a normal distribution curve of PA and the number of subject equivalent to each PAs were drawn for all subjects in Fig. 11. According to this figure, PA50 was selected as -45 deg. representing an S-shaped alignment, while PA10 and PA1 as -57 deg. and -67 deg. representing minor kyphosis and significant kyphosis, respectively. The skeletal alignment of THUMS was modified to PA50, PA10 and PA01 (see the lower images in Fig. 11). Analysing the results of FE simulations by using their HBMs, the belt engagement was small in PA01 model, although the belt did not deviate from the ilium in all cases of PA50, PA10 and PA01 (Fig. 12). The lap-belt force of PA01 was the largest in all, and the amount of belt sliding-up over the ilium of PA01 was 2.37 times to that of PA50. Both the maximum pelvic displacement and rotation increased as the pelvic angle reclined. The detailed observation of the pelvic kinematics revealed that, in PA01, the ischium shifted forward in the initial stage compared to PA50 and PA10. This shift encouraged the pelvis to slide over the seat surface. Furthermore, measuring the influence to kinematics of other parts (head, neck, chest and femur), HIC and C2 moment of PA01 were significantly higher than PA50, 1.58 and 2.72 times respectively (Fig. 13). On the other hand, the chest deflection and femur loads were almost no difference among three models.

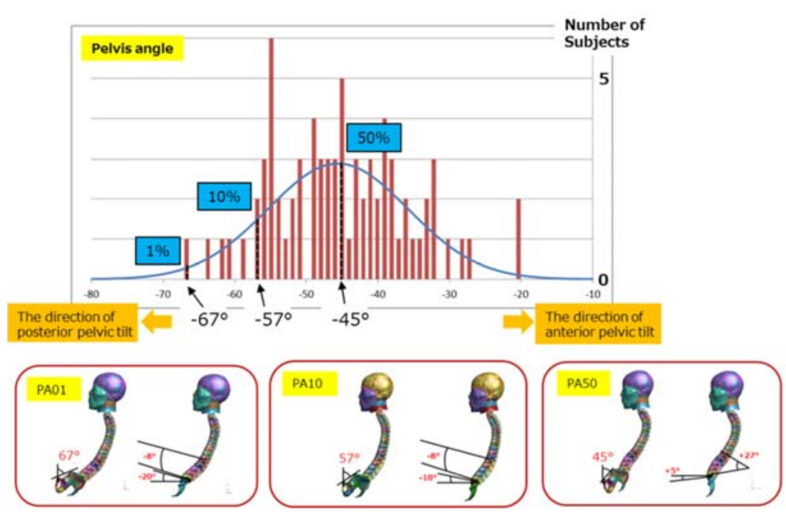


Fig. 11. Normal distribution of pelvic angles and human models equivalent to each percentile.

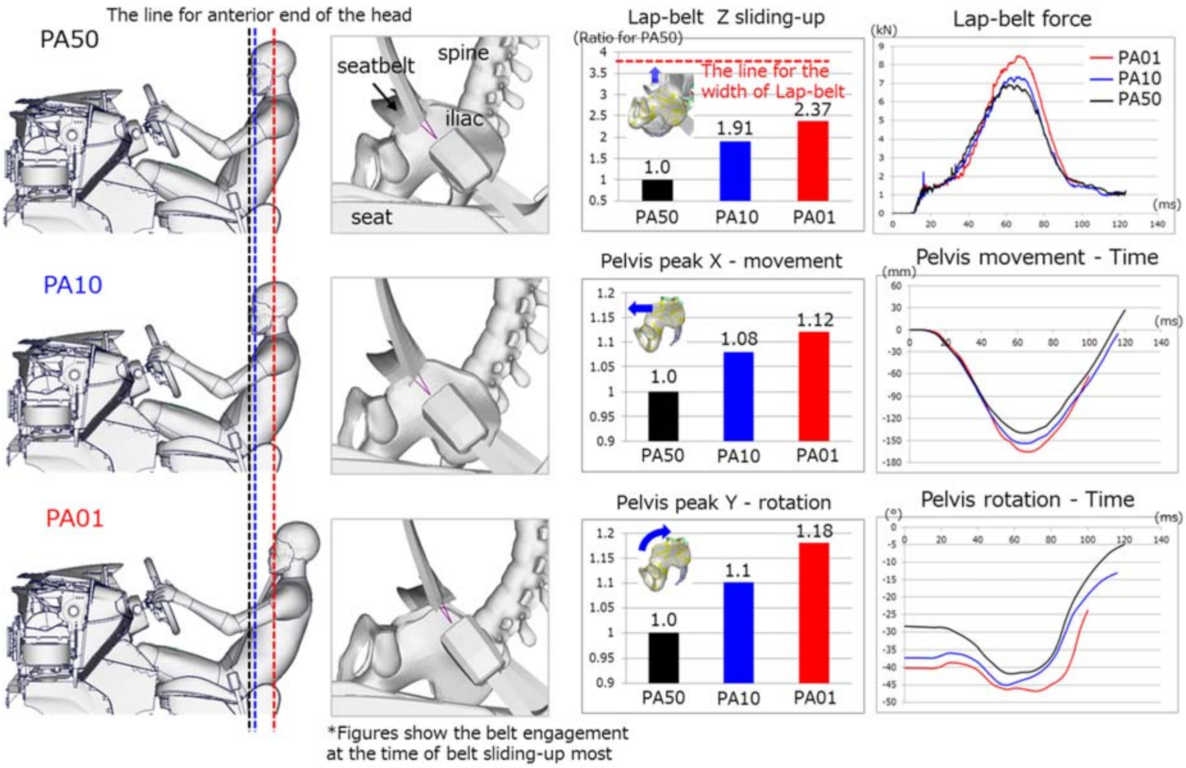


Fig. 12. Kinematics analysis using three models which modified pelvic angle.

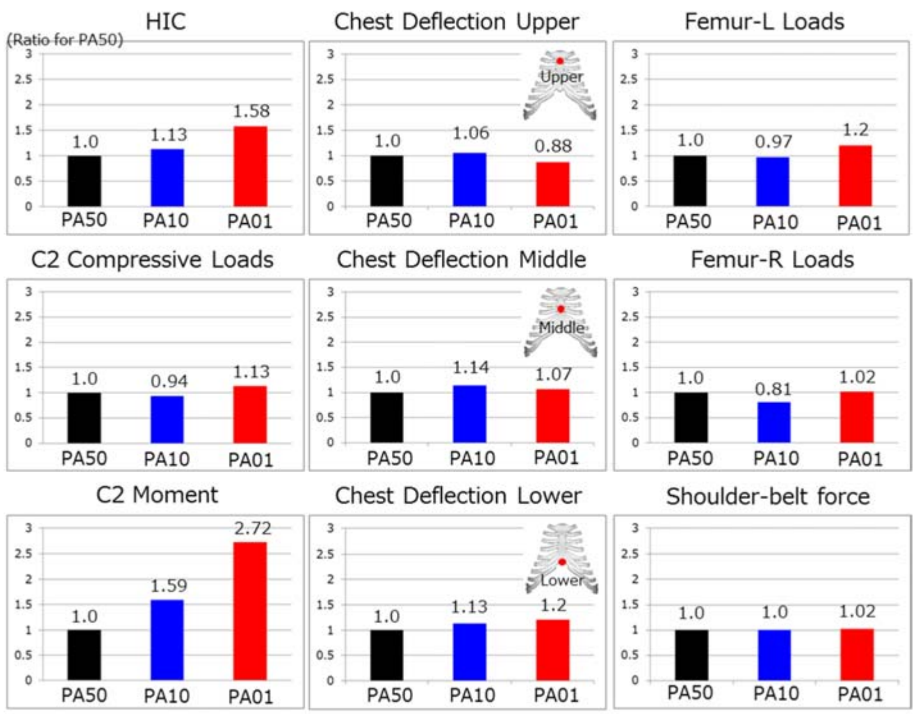


Fig. 13. Kinematics analysis of injury measures to the head, neck, chest and femur.

IV. DISCUSSION

Between subjects with S-shaped spine and those with overall kyphosis, the skeletal alignment varies significantly in terms of the angle from lumbar spine to pelvis. The difference becomes greater especially in the lower part of skeleton as the posture changes. No strong correlation could be observed between PA and human factors such as age, height, and BMI. The observation of X-ray images indicated that there was the large variation in the shape of ASIS, distance between ASIS and the posterior-superior iliac spine (PSIS), and distance between ASIS and the pubic symphysis. These factors seem to affect PA. Therefore, more analysis focused on the individual differences of the pelvic shape is necessary.

Some subjects showed a tendency that the greater the BMI, the more the PA tilts forward. They had highly S-shaped alignment in standing posture. This phenomenon might be due to the condition of muscles such as iliopsoas, erector spinae muscle and quadratus lumborum (Fig. 14). The mechanism of PA tilting forward is as follows: (a) When the iliopsoas muscle declines, the blood circulation around the lower abdomen and pelvis is improved. (b) The metabolism is slowed down and fats are accumulated. (c) To maintain the standing posture, the muscles around the lower back tense. (d) When their tension continues, the abdominal muscles decline and celiac organs move forward (Fig. 15). (e) Because the center of gravity shifts forward and the body also moves forward, the overcorrection of lumbar lordosis is caused to maintain physical body balance.

The reason for the tendency that the higher the BMI, the more anterior pelvic tilt in seated posture has been assumed as follows: as subjects with high BMI have lumbar lordosis as described above, in order to counterbalance, thoracic vertebrae kyphosis occurs, leading to highly S-shaped skeletal alignment in standing posture. Then, even in a seated posture, this S-shaped alignment remains and leads to anterior tilt of PA. Because it suggests that the skeletal alignment in seated posture depends on the alignment in standing posture, further analysis needs to be done as to the correlation of angles between standing and seated posture.

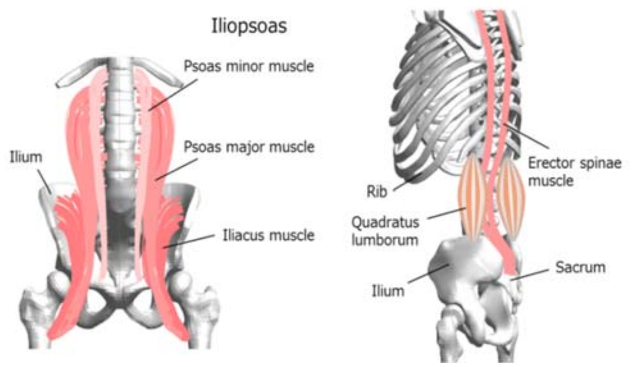


Fig. 14. The location of iliopsoas, erector spinae muscle and quadratus lumborum.

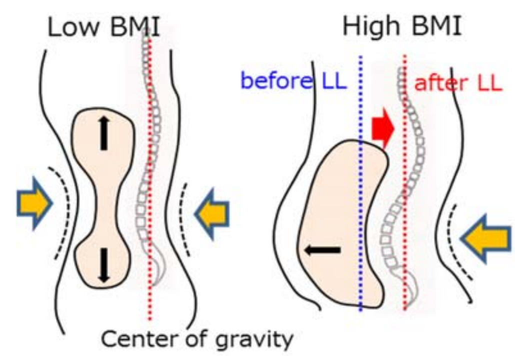


Fig. 15. The relation between BMI and skeletal alignment [13].

The simulation results revealed that, in seated posture, the more the pelvis tilted rearward, the more the pelvis shifted forward and rotated. This is due to the lap-belt sliding up and pushing the upper pelvis, which cause more rotation of pelvis and less constraint by the lap seatbelt. Besides, HIC and C2 moment of PA01 were the highest in all. As with the kinematics of the pelvis, the rearward movement of the upper body due to posterior pelvic tilt induced the deterioration of initial restraint for the upper body, and those situations might affect an increase of the head intrusion to airbag and the neck bending resulting in HIC and C2 moment aggravation (see the red line for PA10 head in Fig. 12). On the whole, in order to restrain the occupant sufficiently in an accident, it is important to maintain occupant posture with a straightened spine and chest stuck out.

Limitations

Since this study only deals with Japanese occupants, its relevance to other ethnicities cannot be discussed. Furthermore, since X-ray photographs are taken with subjects seated in one type of automobile seat in a short time, whether the results are applicable to long-time driving situations is not known. Also, the sampling is not completed and further data analysis needs to be done in the future. To research the influence that an individual difference in the skeletal alignment gives for pelvis kinematics, the three models of the same shape with different alignments were used in this study. In addition, only one human model with a single pelvis shape was used in simulations of occupant kinematics. In the future, the models which modified all angles of the spine and the shape of occupant body referring to data of the subjects should be analysed.

V. CONCLUSIONS

In this study, the skeletal alignments of X-raying 75 volunteers were analysed. Those alignments in seated posture could be classified into two types and neither LL nor PA showed strong correlation to age, height and BMI. By comparing between the skeletal alignment in standing posture and that in seated posture, there was a difference in the skeletal alignment of standing posture between those who with S-shaped alignment and others with kyphosis in seated posture, and it showed significantly wide S-shape in standing posture. HBMs representing three types of pelvic angle: PA50, PA10 and PA01 were created by modifying THUMS ver.4. The simulation results indicated that the belt sliding-up over the ilium, pelvic displacement and rotation might increase as the pelvic tilted rearward, although the belt did not deviate from the ilium in all cases. Additionally, differences of injury measures to the head and neck could also be observed.

VI. ACKNOWLEDGEMENT

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VIII. APPENDIX

Gender	Height(cm)	BMI	Age	Standing posture						Seated posture					
				CC	TK	TLK	LL	SS	PA	CC	TK	TLK	LL	SS	PA
Male	160	37.11	36	4.5	-32.1	-1.8	33.3	27.8	16	9.8	-24.6	-26.0	3.8	-23.8	-35.6
Male	162	21	33	7.3	-26.1	-5.6	43.9	48.6	12.3	-2	-13.1	-12.8	-6.9	-20.3	-59.4
Male	166	21.05	30	8.2	-12.4	7.7	35.6	38.5	4.65	3.3	-15.4	2.4	2.9	-10.6	-44.55
Male	166	23.59	54	10.2	-17.5	-0.8	39.0	37.7	3.47	8.2	-15.6	-3.0	-0.9	-13.9	-48.13
Male	166.3	30.2	42	17.6	-29.6	-7.9	36.95	38.6	6.95	-4.6	-7.7	-12.2	3.3	-23	-55.65
Male	167	20.8	70	-2.5	-29.8	0.6	39.4	32.1	4.91	1.7	-20.9	-6.7	2.5	-18.7	-45.89
Male	167	21.51	34	4.7	-30.3	-18.9	33.0	31.8	5.66	-2.1	-34.0	-28.0	-14.7	-22.3	-48.44
Male	167	39.4	25	9.9	-39.8	-14.3	29.7	26.4	8.39	-14.3	-5	7	2	-12.3	-36.41
Male	168	22.3	26	4	-29.4	-5.9	37.7	21.6	13.9	-8.9	-20.55	-10.7	-4.9	-21	-34.5
Male	168	24.4	38	4.3	-21.03	-18.2	29.48	28.77	-4.3	1.8	-27.4	-18.1	3.9	-8	-38.7
Male	168	36.85	34	-6.0	-17.3	6.2	36.6	39.3	16.8	-6.4	-8.9	-7.7	-3.3	-19.1	-41.6
Male	169	17.51	30	9.3	-29.7	-0.6	30.3	35.4	6.9	4.8	-18.0	-11.9	-17.1	-33.3	-61.8
Male	170	17.65	32	20.0	-21.8	8.1	45.6	40.6	14.8	11.9	-11.6	-4.6	3.6	-7.8	-33.6
Male	170	19.37	37	12.5	-30.9	-12.3	18.7	19.3	-3.39	6.8	-30.6	-15.7	-11.3	-22.6	-51.79
Male	170	19.7	36	10.6	-21.37	-5.24	33.3	37.42	4.5	-2.6	-21.9	-10.5	-7	-18	-57.6
Male	170	20.07	47	24.6	-32.7	-12.7	37.2	32.4	9.66	12.6	-26.5	-7.7	-7.2	-16.9	-39.64
Male	170	20.8	55	21.8	-17.5	-8.64	9.26	29.5	0.69	5.3	-23.2	-16.85	2.3	-9.5	-33.11
Male	170	21.11	56	-4.4	-14.3	-5.1	27.6	20.6	-9.37	-3.1	-11.7	-1.1	6.6	-12.5	-42.47
Male	170	21.45	37	14.2	-19.8	-3.1	26.0	37.2	1.88	-7.6	-19.1	-7.3	-3.4	-17.6	-52.92
Male	170	22.49	28	7.7	-34.3	-14.4	30.8	26.3	-4.44	-1.4	-16.0	-12.1	1.6	-14.9	-45.64
Male	170	22.49	62	19.4	-20.2	3.8	30.1	24.6	-7.8	-0.7	-18.6	-2.1	5.3	-11.1	-43.5
Male	170	24.9	36	9.6	-20.9	-11.05	13.5	20.1	10.79	1.9	-15.6	-11.2	-1	-19	-38.51
Male	170	25.95	47	-0.8	-16.5	-0.7	39	39.6	8.56	-9.6	-22.4	0	18.8	2.3	-28.94
Male	170	36.68	28	-2.4	-3.4	-5.4	26.6	32.4	10.5	0.9	-15.1	-10.0	-15.1	-17.2	-39.1
Male	171	21.89	66	13.7	-23.7	-0.6	23.5	37.5	-3.57	12.8	-24.7	-4.8	-2.4	-20.4	-57.27
Male	171	22.23	46	-7.5	-23.8	-17.6	33	20.2	9.48	-19.9	-15.2	-12.8	11.7	-14.8	-30.02
Male	171	24.62	34	11.2	-28.2	-7.7	44.4	45.3	15.96	-16.6	-19.0	-15.4	-0.6	-17.7	-47.04
Male	171	24.62	66	12.1	-21.7	-6.5	26.2	27.3	-6.59	-1.1	-23.7	-8.5	2.7	-13.4	-47.29
Male	171	34.88	53	-3.7	-23.2	1.7	34.5	44.1	8.7	-12.8	-14.2	-11.1	6.0	-7.6	-43
Male	172	30.42	57	24.9	-46.2	-16.2	44.5	36.3	-10.17	5.4	-38.7	-13.6	26.3	2.7	-43.74
Male	173	21.7	58	17.8	-34.05	-27.3	30	23.9	2.44	8.8	-32.6	-30.3	12.9	-13.2	-32.46
Male	173	26	24	0.76	-11.3	1.1	18.85	27.7	6.98	-10.8	-10	-13.85	-22.2	-26.3	-47.82
Male	173	26.1	48	-1.1	-16.44	-10.7	33.4	27.6	-3.5	-16.1	-20.5	-18.6	2.6	-21.6	-51.5
Male	173	41.1	43	15.2	-41.5	-6.9	23.3	20.6	-11	4.2	-44.1	-6.4	12.4	-9.7	-41.3
Male	174	20.81	60	12.4	-23.4	-3.0	32.1	24.6	-6.7	3.3	-18.9	-4.5	10.5	-7.8	-39.1
Male	174	26.75	67	-1.2	-26.8	-3.0	27.3	46.6	-10.9	-3.6	-15.3	-9.7	-0.7	2.5	-55
Male	174	42.6	28	-4.1	-36.1	0	40.9	45.6	11.23	-9.3	-26.9	-7.2	6.5	5.1	-32.37
Male	175	22.9	25	-3.3	-22.2	-1.3	34.2	32.2	4.88	-0.7	-23.75	1.7	-0.4	-27.5	-56.02
Male	176	23.89	47	10.3	-15.3	-6.0	36.2	40.4	7.51	9.2	-29.1	-5.6	2.4	-13.7	-46.59
Male	177	17.9	24	-5.6	-30.6	-14.6	40.6	41.1	2.06	-25.8	-25.5	-21.5	17.4	-2.7	-37.84
Male	177	25.2	50	15.3	-32.8	-14.6	43.9	47	9.15	6.6	-26.8	-12.4	6.7	-16.6	-48.25
Male	177	25.22	48	-1.0	-20.9	-14.4	38.4	36.9	1.55	6.8	-15.7	-23.4	-6.5	-18.8	-54.15
Male	178	25.88	38	2.6	-18.03	4.8	31.4	30	4.17	-2.1	-23	-2.5	-1.7	-13.9	-42.73
Male	182	21.74	29	-5.1	-27.4	-14.5	29.5	38.1	-1.55	1.4	-9.7	-12.9	-5.8	-22.4	-62.05
Male	187	20.6	50	2.4	-20	-9.3	24.1	32	10.6	-5.2	-22.2	-7.6	-0.9	-19.1	-36.4
Average	171.20667	25.2318	42.5333	6.89689	-24.718	-6.5073	32.2853	33.1464	3.83867	-1.3289	-20.511	-10.396	0.90444	-14.844	-44.654
Standard deviation	4.6718257	6.34885	13.1362	8.81254	8.38343	7.74958	7.97999	8.09022	7.70427	8.83281	8.01995	7.75869	9.20521	8.12765	8.69256

Table 1. Characteristics of the subjects and each angle (Male).

Gender	Height(cm)	BMI	Age	Standing posture						Seated posture					
				CC	TK	TLK	LL	SS	PA	CC	TK	TLK	LL	SS	PA
Female	145	22.3	57	-9	-14.9	-1.1	33.4	37.8	-12.6	-8.7	-22.5	-6.4	6.9	-17.6	-67.2
Female	147	26.7	62	6.8	-19.5	1	29.2	21.8	5.42	-2	-30.8	-16.1	1.6	-30.5	-55.78
Female	148	20.09	41	20.5	-39.0	-3.2	33.2	32.5	1.14	6.3	-32.9	-5.0	-9.7	-32.8	-64.16
Female	149	22.5	62	-3.6	-23.9	-15	30.8	30.3	2.78	-17.6	-23	-19.2	-6.1	-19.7	-45.42
Female	149	23.4	54	22.6	-23.7	8	35.8	47	0	-6	-22.8	-1.88	8.8	-7.9	-49.8
Female	150	20	29	0.7	-25.9	1.0	44.4	40.4	13.6	-5.5	-33.5	-18.9	-10.4	-20.0	-46.8
Female	151	23.9	61	7.8	-28.4	-5	24.1	25.1	-6.11	-5.8	-33.3	-8.6	-5	-21.6	-49.91
Female	151.5	21.35	60	-7.7	-21.1	0.9	22.9	27.9	5.36	7.4	-27.5	-14.2	-5.2	-20.5	-45.44
Female	152	19.04	52	4.6	-28.9	-6.9	34.6	28.2	1.96	-0.8	-28.7	-16.6	-2.8	-30.7	-56.94
Female	152	23.81	42	-8.2	-15.5	-10.7	29.5	32.4	4.32	-10.2	-11.8	-17.7	-15.6	-27.9	-55.98
Female	153	22.21	63	10.4	-15.9	11.7	48.2	48.6	3.58	7.9	-19.9	-4.4	14.8	-4.3	-49.32
Female	153.5	18.67	32	-1.6	-30.2	-14.0	40.6	32.4	2.11	-14.2	-25.2	-12.0	7.1	-11.7	-41.99
Female	154	27.41	46	1.4	-24.2	0.0	32.9	25.8	2.88	-1.1	-22.3	-11.5	-15.3	-32.3	-55.22
Female	154	30	59	20.7	-29.6	0.5	41.6	37.2	30	4.8	-11.3	-13.8	4.5	-16.5	-20.2
Female	154	31.62	36	-15.1	-23.7	-5.1	50.4	34.7	-10.3	1.2	-12.9	-8.8	11.1	-10.5	-55.5
Female	155	17.5	58	7	-25.6	-10.5	27.5	20.4	-5.2	-5.7	-27.4	-10.3	-4.9	-27.2	-46.5
Female	155	21.64	63	14.9	-38.7	2.7	33.3	31.7	20.2	7.6	-37.2	-8.7	20.9	-9	-27.6
Female	155	22.48	48	5.0	-24.4	-11.9	41.0	27.2	-3.9	4.0	-22.8	-20.2	-0.1	-22.3	-53.4
Female	156	20.5	53	-14.2	-24.7	-3.9	28.2	36.1	15.4	-24.5	-28.5	-19.1	-3	-23.2	-40.1
Female	156	22.6	49	6.0	-28.7	-7.3	26.0	14.0	-8.3	-2.1	-26.7	-15.2	-2.1	-26.8	-49.1
Female	158	18.83	44	-5.0	-7.7	4.4	42.6	45.3	7.78	-8.4	-19.1	-15.2	10.1	-7.7	-45.22
Female	159	20	45	-16.9	-21.2	-5.1	27.6	33.2	1.7	-14.8	-22.5	-18.3	2.3	-24.9	-54.9
Female	160	17.97	26	-6.3	-16.3	-15.7	27.5	28.6	6.2	-5.1	-9.8	-3.3	-5.4	-9.6	-32
Female	160	19.9	57	19.2	-14.7	10	25.4	18.67	3.23	7.4	-22.3	-8.9	-8.8	-23.8	-40.87
Female	161	19.29	69	6.2	-24.7	1.6	38.4	39.0	3.15	1.2	-19.4	-6.6	16.9	-2.3	-38.15
Female	162	19.05	63	10.8	-29.5	-21.8	26.8	35.4	19.5	-1.3	-29.4	-20.6	3.1	-23.1	-20.9
Female	163	21.8	58	19.9	-31.3	-4.7	33.8	27.8	-2.88	12.1	-31	-11.8	3.5	-25.5	-56.08
Female	163.4	22.4	50	10.7	-30.3	-8.4	34.3	29.04	-3.3	10	-30	-20.5	8.8	-18.2	-51.8
Female	164	22.31	54	9.6	-30.6	0.7	48.8	51.3	0	3.3	-35.1	-5.7	-26.0	-1.1	-52.4
Female	168	27.64	26	-8.5	-7.3	-11.0	15.9	17.5	-1.65	-18.3	-5.4	-8.4	-7.6	-20.8	-39.95
Average	155.28	22.2303	50.6333	3.62333	-24.003	-3.96	33.6233	31.9103	3.20233	-2.63	-24.167	-12.263	-0.2533	-19	-46.954
Standard deviation	5.5066868	3.41338	11.6289	11.1626	7.52376	7.72552	8.1545	8.94321	9.0837	9.03199	7.84204	5.60792	10.2016	8.92932	10.9703

Table 2. Characteristics of the subjects and each angle (Female).