Thoracic and Lumbar Spine Pedicle Morphology in Japanese patients

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Abstract

Purpose

Pedicle morphology is important for intraoperative surgical anatomy and to define pedicle screw design and parameters. However, differences of pedicle size according to ethnicity and gender are not well studied. The purpose of this study is to investigate morphological characteristics of the pedicle in Japanese patients for determining adequate screw size and optimal surgical planning.

Methods

We investigated thoracic and lumbar pedicle morphology in Japanese patients using computed tomography (CT) measurements and analyzed the standard size of pedicles on upper thoracic to lumbar spine CT images in 227 Japanese patients.

Results

Gender had a larger impact on the shape and size of pedicles than racial differences. In the distribution of pedicle width, we calculated the ratio of values less than 4.5 mm, that in females resulted to be over 30% for the Th3 ~ Th9 segment, and particularly high, above 60% at Th4 and Th5.

Conclusion

Our measurement analysis showed that pedicle morphological parameters in Japanese patients showed tendency to be smaller to those found in other studies, and particularly in female patients, they were statistically significantly smaller. Adequate trans-pedicular instrumentation for Japanese patients will

require smaller size pedicle related devices that will match our anatomical findings to achieve safe device placement. In addition, serving ethnically non-homogenous patient population can require further to spinal morphometric for precise device selection.

Keywords

pedicle, spine, lumbar, morphology, pedicle screw

Declarations

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Ethics approval: All patients' information is anonymized before being included in the study. We have obtained the approval required by the Ethical commission of our university, as # 32-232(10313).

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Informed consent: All patients' information is anonymized before being included in the study and the study information and contact address are published in the website of our university.

Introduction

The number of patients suffering from spinal degenerative diseases tends to increase with the increase of life expectancy. Transpedicular fixation surgery has been developed as an important treatment and has become a standard in the internal fixation surgery [6, 14, 27]. In particular, fixation using pedicle screws is a surgical procedure that became routine for spinal surgeons, due to its high effectiveness.

To perform this surgical procedure safely and effectively, anatomical understanding of the vertebrae including the pedicles is essential and many anatomically oriented studies have been conducted [3-5, 8, 13, 15, 19, 20, 22, 23, 26, 29]. However, many of the reports have studied different ethnicity and particularly reports based on Asian population are lacking [3, 7, 10-12, 16, 17, 25, 26, 28]. There are few reports studying the Japanese population, but particularly reports on the thoracic spine are limited [12, 16, 17]. Although gender-based differences have been reported in some past studies [3, 8, 9, 11, 16, 23], this aspect also has not been adequately analyzed. If considered previous studies, the screw device sizes currently available may not be appropriate for part of Asian or female patients. In cases, screw placement and screw size selection have been carried out based on clinical experience, and correct and safe pre-operative planning could be made only with adequate morphometric study of pedicle parameters.

The purpose of this study was to obtain adequate anatomic understanding of the vertebrae focused on the pedicle in Asians, for proper screw size determination and safe planning. In this study, we consistently measured the pedicle size from the upper thoracic to the lumbar spine and calculated the standard pedicle size taking into consideration gender difference in more than 200 Japanese patients. To the best of our knowledge, this is the largest measurement study population of a single ethnicity.

Methods

In order to reflect the actual clinical environment related to surgery, measurements were performed on the images of adult patients who were considered for spinal surgical treatment. We used pre-operative computed tomography (CT) images of the thoraco-lumbar spine of adult patients who were hospitalized for surgery on the thoracic or lumbar spine in our institution from January 2013 to June 2019. In this study we have obtained the approval required by the Ethical commission of our institution, as # 32-232(10313). In cases with lumbosacral transitional vertebra (LSTV), LSTV measurements were also taken. The total number of hospitalized spinal disorder patients was 346. Out of them, pre-operative images had 229. Two patients were excluded because of bone tumor pathology, there for finally remained 227 patients for analysis, or 1,474 vertebrae with clear pre-operative images. Out of these vertebrae we removed additionally 21 due to significant compression fractures or pathological degeneration. The final number of cases was 227 (145 males, 82 females) and 1,453 vertebrae were measured. The mean ± standard deviation age of the male and female patients was 67.0 ± 13.1 years and 66.5 ± 15.2 years, respectively.

The models of the CT devices used were SOMATOM Perspective (Siemens Healthcare, GmbH, Forchheim, Germany, SOMATOM Emotion 16 (Siemens Healthcare, GmbH, Forchheim, Germany), SOMATOM Definition Flash (Siemens Healthcare, GmbH, Forchheim, Germany), Aquilion PRIME (Canon medical systems corporation, Ohtawara, Japan), SOMATOM Definition AS+ (Siemens Healthcare, GmbH, Forchheim, Germany), and SOMATOM Sensation16 (Siemens Healthcare, GmbH, Forchheim, Germany). The typical scan parameters were as follows: 128×0.6 mm detector configuration, 0.8 pitch value, 1.0 s per rotation, tube voltage 120 kV, quality ref. mAs 150 (using Care Dose4D). Coronal, sagittal and axial images were reformatted with slice thickness of 2.5 mm and were sent to PACS server. We used liquid-crystal display that has resolution of 1280×1024 dots (FUJIFILM Corporation, Tokyo, Japan) in analysis. The distance measurement function part of the software is used manually, and with the experienced user is yielding differences in measurement of 0.02 mm in the horizontal/vertical planes to 0.03 mm at measurements at 45°deg, with the necessary image magnification if required. This resolution was considered appropriate for the purposes of the measurement intending differences of 0.5 mm to 1.0 mm. For each vertebra, each parameter was measured on the left and right side. SYNAPSE software ver. 4.1.0 (FUJIFILM Corporation, Tokyo, Japan) was used for image analysis. Stata ver.13 (StataCorp, College Station, USA) was used for statistical analysis for every parameter. The parameter was a continuous variable and was showing a normal distribution, all the data were analyzed using the parametric t-test between 2 groups that determined significant differences ($P < 0.05$).

Measured parameters:

Pedicle Height:

In sagittal images, the narrowest portion of the pedicle in the direction perpendicular to the endplate was defined as the pedicle height [29] (Figure 1A).

Pedicle Width:

The narrowest part of an axial slice of the pedicle was defined as the pedicle width [5] (Figure 1B).

Pedicle Axis Length:

In axial slices, the perpendicular bisector of the narrowest portion of the pedicle was defined as the pedicle axis, and pedicle axial length was determined as the distance from the posterior aspect of the laminar cortex to the anterior aspect of the cortex of the vertebrae along the pedicle axis [29] (Figure 1C).

Pedicle Transverse Angle:

In axial slices, the angle formed between the midline of the pedicle axis and the midplane on the axial images of the vertebra was defined as the pedicle transverse angle. The medially directed axis was considered positive (+) and the laterally directed – as negative (-) [19] (Figure 1D).

We measured each parameter on CT images (Figure 2). All measurements were carried out by the same neurosurgeon (K.M.).

Results

Left/right symmetry:

Each parameter (left and right) was measured separately to determine the degree of left/right symmetry (Table 1A). For the pedicle transverse angle, significant differences were found in Th1, Th2, and the entire lumbar spine except for LSTV (Table 1B). However, apparent left/right asymmetry was not observed for other parameters (Table 1A). Therefore, in the measurements that followed, analysis was performed without distinction between the left and right for all parameters.

Gender difference:

Based on past studies, data for male and female patients were analyzed separately for all parameters. In all the vertebrae except for LSTV, pedicle height, pedicle width, and pedicle axis length of the female patients were significantly smaller than those of male patients (Table 2).

Pedicle Height:

The pedicle height was smallest at Th1 (male: 9.6 mm ± 1.2 mm, female: 9.2 mm ± 0.8 mm) and increased gradually, being the largest at Th12 (male: 18.2 mm ± 1.7 mm, female: 16.6 mm ± 1.3 mm). Subsequently, the value gradually decreased over the lower lumbar spine (Table 2).

Pedicle Width:

The pedicle width was smallest at Th4 (male: 4.9 mm ± 1.2 mm, female: 4.1 mm ± 0.9 mm), and gradually increased till Th12 to decrease again in the upper lumbar spine. Subsequently, the value increased again toward the lower lumbar spine, being the largest at LSTV (17.1 mm ± 2 mm) in males and at L5 in females (14.1 mm ± 2.1 mm) (Table 2).

In the distribution of the pedicle width, we calculated the ratio of the values less than 5.5 mm.

The value in the male patients was more than 30% at Th3 ~ Th9, remarkably close to 70% at Th4 and Th5, and only 5.7% at L1. The value in females was over 70% at Th3 ~ Th8 and 22.8% at L1 (Figure 3).

In the distribution of the pedicle width, we also calculated the ratio of the values less than 4.5 mm. The value in the male patients was more than 30% at Th4 ~ Th6 and only 1.3 % at L1. The value in the female patients was over 30% at Th3 ~ Th9 levels. Notably, it was over 60% at Th4 and Th5 and 9.4% at L1 (Figure 3).

Pedicle Axis Length:

The pedicle axis length was smallest at Th1 (male: 35.8 mm ± 2.9 mm, female: 33.5 mm ± 2.3 mm). It was observed to gradually increase and was the largest at L3 (56.5 mm ± 4.6 mm) in the male and at L4 (51.1 mm ± 3.6 mm) in the female patients. Further on, the value became slightly smaller in the lower lumbar area (Table 2).

Pedicle Transverse Angle:

The left transverse angle of the pedicle was largest at Th1 (male: 32.4 ° ± 4.4 °, female 34.3 ° ± 4.9 °) and it was observed to decrease to its lowest value at Th9 (male: 3.6 ° ± 7.0 °, female: 4.3 ° ± 3.8 °). Further on down, it gradually increased in a similar way to the values of Th1 at LSTV. The right transverse angle of the pedicle was largest at Th1 (male: 28.4 ° ± 5.4 °, female 28.9 ° ± 3.6 °) and it was observed to decrease to its lowest value at Th8 (4.1 ° ± 3.3 °) in male patients and Th11 (4.8 ° ± 4.6 °) in female patients. Further on down, it gradually increased in a similar way to the values of Th1 at LSTV. The left side angles had tendency to be larger than those on the right side (Table 1B).

In the analysis performed without distinction between left and right, the transverse angle of the pedicle was largest at Th1 (male: 30.4 ° ± 5.3 °, female 31.6 ° ± 5.1 °) and it was observed to decrease to its lowest value at Th8 (3.9 ° ± 3.1 °) in male patients and Th9 (4.6 ° ± 3.3 °) in female patients. Further on down, it gradually increased in similar way to the values of Th1 at LSTV (Table 2).

Discussion

Selection of parameters of pedicle morphology:

In the current study, we analyzed pedicle morphology in an environment closest to the clinical application of these parameters. This study included 227 patients, and to the best of our knowledge it is the largest study of ethnically homogenous population. Additionally, our study included only admitted for treatment hospital patients to obtain a better understanding of the actual patient population under management. In past studies has been already found that pedicle morphology did not change significantly with degenerative disease [17, 21]. Therefore, the current study included only spinal degenerative disease patients.

Implications for the angle of insertion:

When placing an implant device, it is necessary to select its adequate size that will properly fit the corresponding vertebral structures and past studies on transpedicular screw application have established the key parameters for appropriate size analysis and selection. Ebraheim et al. [8] and Olsewski et al. [19] established the pedicle transverse angle as the screw insertion direction, and took the width and height of the narrowest part of the pedicle to determine the screw maximum diameter. The pedicle axis length that will determine the length of the screw was also measured. Among these parameters, pedicle transverse angle, pedicle height, and pedicle width were compared with past studies as key parameters, aiming to avoid structural damage. Hou et al. [10] and Cheung et al. [7] defined the pedicle axis by aiming to a point on the anterior surface of the vertebral body in the mid-sagittal plane as the end point. However, Scole et al. [23] set the pedicle axis more consistently with the shape and direction of the pedicle, tracing a more laterally directed angle to ensure a longer intra-pedicular axis length and screw trajectory. With the same aim, we defined the axis using the midpoint of the smallest transverse pedicle diameter, and traced the pedicle axis perpendicular to it, as has been used in the majority of publications on the subject. As for a device size oriented, we defined the pedicle axis in the same way as Scole et al. [23], and pedicle width, pedicle height, pedicle transverse angle, and pedicle axis length were defined and measured as parameters.

Gender and ethnic differences on pedicle morphology

Although not discussed in the past, more recent studies addressed the impact of gender differences and the choice of device size [3, 8, 16]. In this study, the significant differences demonstrated that gender is an important factor to be considered in the selection of appropriate device size.

Regarding ethnicity, the overall characteristics of the pedicle shape and size in Japanese patients is having similarities to those found in other reports on Asian ethnical groups. Such similarity for the pedicle width, which is minimal at Th4 can significantly affect the choice of screw diameter. (Figure 4).

Again, having to exclude the historical studies on gender and ethnically unspecified material [5, 11, 16, 23], more recent studies indicate the possibility for Asians to have smaller pedicle width compared to the found on the other diverse ethnicities investigated [8, 10, 17, 19, 25], as that can be seen from the comparative figure of existing studies internationally (Figure 5). While treating patients from populations of diverse ethnicity, proper reference to the spinal morphometric ranges can be very helpful for the proper selection of spinal fixation devices.

Pedicle width distribution and implications on screw diameters:

Taking the above information into consideration, the proper screw diameter choice is important and has been pointed out by many studies in the past [1, 4, 21]. However, reviewing current available thoracolumbar fixation devices, they contain transpedicular components (screws and others) with a minimum lineup of 4.5 mm, and we often use screws of diameter 5.5 mm or more attempting to prevent screw loosening. If we consider the pedicle width established in this study, given the ratio of 4.5 mm and 5.5 mm diameter pedicles (Figure 3), especially in female patients, the majority of patients have upper-middle thoracic pedicles of less than 5.5 mm. Adding to them those with less than 4.5 mm diameter, there is clear discrepancy between used screws and our measurement findings. According to this analysis, a proper sized screw matching our data does not exist at present.

The need of device parameters modification

In past studies, there have been few reports about the ratio of width values less than 4.5 mm. Nojiri et al said that the ratio of less than 4mm width was 17% at T8, and 13.1% at T9, therefore in such cases there was a high probability that a 4-mm screw would destroy the pedicle wall [16]. The use of oversized screws will lead to complications such as pedicle fractures, evident from previous reports [24]. It is considered that the size of currently used screws is based on the result of measuring male and female individuals of different ethnicity, and it is presumed that there is a tendency to "oversize" in Asian females. Therefore, many cases are facing serious complications during thoracic surgical operations. To avoid these risks, a smaller diameter screw would be desirable, however, if we continue downsizing, it would be difficult for titanium alloys or other metals to provide the necessary strength required for such devices. Hence, additional downsizing would result in screw loosening and even implant breaking, and actually very few metal screws under 4.5 mm diameter existed at present. Other types of devices (such as Interlaminar Lumbar Instrumented Fusion devices, sublaminar wires, and so on) were also used in some patients for spinal fixation, but those are not superior to pedicle screw systems regarding stabilization reliability, so pedicle screws will continue to be an important implant in spinal surgery in the future [2, 18]. As this issue presents an unsolvable dilemma, a smaller device cannot be the solution, but the development of new concept devices and materials are required. For example, plastic including poly-ether-ether-ketone (PEEK) or carbon fiber reinforced plastics are used for many types of orthopedics devices, and they have the potential to be applied to pedicle screws. For such purposes, the detailed measurements the vertebral dimensions and structures is extremely important.

Limitation:

The limitation of this study is that the measurements were performed by a single neurosurgeon, and that has been also in the majority of the previously published papers [1, 3, 13, 15, 26, 27]. If possible, the measurement by two or more observers or multiple measurements can potentially improve data reliability, and such approach was applied in only 3 of the previous studies [16, 25, 28]. Apparently, our results do not show significant contradiction to past studies results, but methodologically we have to consider it as deficiency.

Conclusions

Our measurement analysis showed that pedicle morphological parameters in Japanese patients showed certain tendency to be smaller to those found in other studies, and particularly in female patients, they were statistically significantly smaller. These findings suggest that an adequate trans-pedicular instrumentation will require smaller size of implants that will match our anatomical findings to achieve safe transpedicular device placement. Such difference in spinal morphometric parameters can be important for implants selection while treating patients of diverse ethnicity.

Authors' contributions

Kohei Morita: Project development, Data collection and management, Data analysis, Manuscript writing

Hiroki Ohashi: Project development, Manuscript editing

Daichi Kawamura: Project development

Satoshi Tani: Project development, Manuscript editing

Kostadin Karagiozov: Protocol/project development, Manuscript writing/editing

Yuichi Murayama: Project development, Manuscript editing

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Figure Legend

Figure 1. Measurements of each parameters. (A) pedicle height, (B) pedicle width, (C) pedicle axis length, (D) pedicle transverse angle.

Figure 2. Measurements of each parameter on CT images. (A) pedicle height, (B) pedicle width, pedicle axis length, and pedicle transverse angle.

Figure 3. Distributions of pedicle width.

Figure 4. Results and a comparison of studies including current one.

Figure 5. A pedicle width comparison with studies under similar conditions (females).

Table 1A. The results of pedicle measurement and left/right symmetry

		Th1	Th2	Th3	Th4	Th5	Th6	Th7	Th8	Th9	Th10	Th11	Th12	L1	L2	L3	L4	L5	LSTV
Male	Pedicle Height (mm)		*										*		*				
	Pedicle Width (mm)																		
	Pedicle Axis Length (mm)		*													**			
	Pedicle Transverse Angle(deg)	*	*											**	**	**	**	**	
Female	Pedicle Height (mm)													*					
	Pedicle Width (mm)										*								
	Pedicle Axis Length (mm)	**															*		
	Pedicle Transverse Angle(deg)	**	**											*	**	**	**	**	

* : 0.01≦P<0.05 ** : P<0.01

Table 1B. The results of pedicle transverse angle with distinction between the left and right (deg)

	Male		Female	
Level	Left	Right	Left	Right
Th1	32.4 ± 4.4	28.4 ± 5.4*	34.3 ± 4.9	28.9 ± 3.6*
Th2	23.5 ± 5.3	19.3 ± 4.4*	21.1 ± 3.6	17.1 ± 3.5*
Th3	12.7 ± 5.1	11.9 ± 4.4	12.7 ± 3.7	11.7 ± 4.3
Th4	9.9 ± 4.0	9.1 ± 4.4	7.4 ± 3.0	6.9 ± 3.1
Th5	8.1 ± 4.0	7.3 ± 4.0	6.9 ± 3.2	5.9 ± 3.1
Th6	6.2 ± 4.0	6.5 ± 4.6	5.2 ± 2.6	4.5 ± 3.2
Th7	5.8 ± 3.4	5.3 ± 3.7	5.4 ± 2.4	4.3 ± 3.0
Th8	3.7 ± 3.0	4.1 ± 3.3	4.6 ± 3.4	5.2 ± 4.1
Th9	3.6 ± 7.0	4.4 ± 2.9	4.3 ± 3.8	4.9 ± 2.9
Th10	4.5 ± 2.0	4.2 ± 3.9	5.0 ± 3.9	5.4 ± 3.3
Th11	4.5 ± 4.1	4.6 ± 3.7	5.1 ± 5.3	4.8 ± 4.6
Th12	5.5 ± 3.2	5.0 ± 3.9	8.1 ± 8.0	6.4 ± 6.3
L1	11.4 ± 3.7	10.0 ± 3.1*	11.8 ± 3.8	10.3 ± 3.6*
L2	12.7 ± 4.9	11.1 ± 3.1*	11.3 ± 3.5	9.9 ± 3.0*
L3	15.3 ± 3.8	13.2 ± 3.5*	15.1 ± 3.9	13.0 ± 4.1*
L4	17.0 ± 4.4	15.0 ± 3.8*	18.5 ± 4.9	15.2 ± 3.9*
L5	27.5 ± 5.4	23.4 ± 5.1*	29.6 ± 6.7	25.2 ± 5.0*
LSTV	27.4 ± 6.9	26.0 ± 5.1	30.0 ± 7.1	26.5 ± 0.7

Data are given as means and standard deviations.

* Statistically significant compared with the value for left ($P < 0.05$).

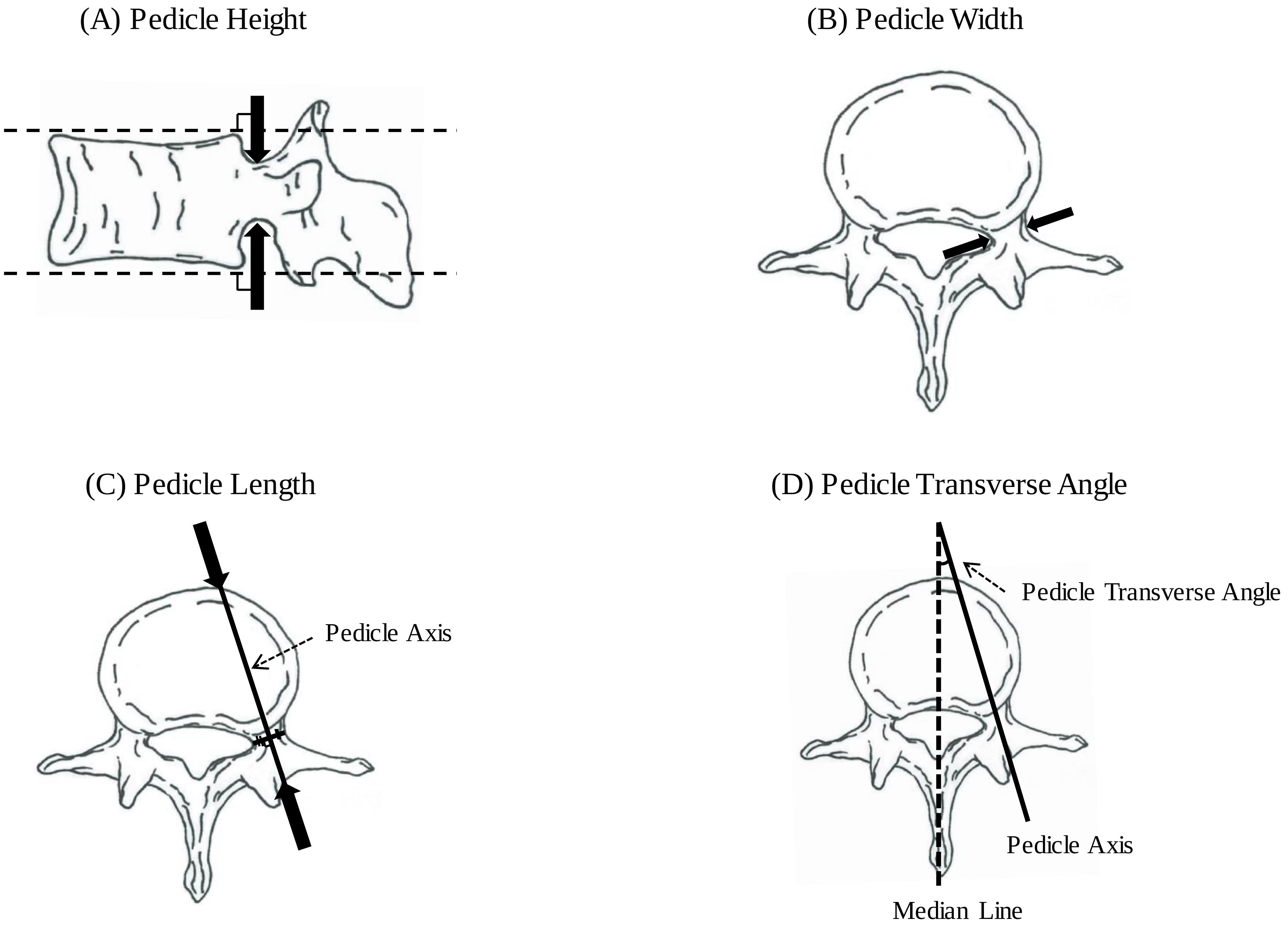
Table 2. The results of Japanese pedicle measurement

	Pedicle Height (mm)			Pedicle Width (mm)			Pedicle Axis Length (mm)			Pedicle Transverse Angle (°)		
Level	All	Male	Female	All	Male	Female	All	Male	Female	All	Male	Female
Th1	9.4 ± 1.1	9.6 ± 1.2	9.2 ± 0.8*	8.7 ± 1.3	9.2 ± 1.3	8.1 ± 1.1*	34.7 ± 2.9	35.8 ± 2.9	33.5 ± 2.3*	31 ± 5.2	30.4 ± 5.3	31.6 ± 5.1
Th2	10.9 ± 1.3	11.5 ± 1.2	10.3 ± 1.1*	6.9 ± 1.3	7.5 ± 1.4	6.3 ± 1*	35.4 ± 2.9	37.1 ± 2.6	33.8 ± 2.2*	20.3 ± 4.8	21.4 ± 5.3	19.1 ± 4*
Th3	11.6 ± 1.4	12.3 ± 1.3	10.9 ± 1.2*	5.3 ± 1.1	5.7 ± 1.1	4.9 ± 0.9*	36.9 ± 3.1	38.4 ± 3.3	35.4 ± 2.2*	12.2 ± 4.3	12.3 ± 4.7	12.2 ± 4
Th4	11.5 ± 1.4	12 ± 1.2	10.8 ± 1.2*	4.5 ± 1.1	4.9 ± 1.2	4.1 ± 0.9*	38.3 ± 3.9	40.3 ± 3.5	35.9 ± 2.9*	8.4 ± 3.8	9.5 ± 4.1	7.1 ± 3*
Th5	11.5 ± 1.4	12 ± 1.3	10.9 ± 1.3*	4.6 ± 1	5 ± 1.1	4.2 ± 0.8*	39.2 ± 3.6	41 ± 3.6	37 ± 2.1*	7.1 ± 3.6	7.7 ± 4	6.4 ± 3.1
Th6	11.6 ± 1.4	12.1 ± 1.4	10.9 ± 1.2*	4.8 ± 1.1	5.1 ± 1.1	4.4 ± 1*	39.8 ± 4.8	41.9 ± 5	36.9 ± 2.5*	5.7 ± 3.8	6.3 ± 4.3	4.9 ± 2.9
Th7	11.8 ± 1.4	12.4 ± 1.3	11.1 ± 1.1*	5 ± 1	5.4 ± 1	4.6 ± 0.9*	41 ± 4.4	43.1 ± 4.4	38.2 ± 2.4*	5.3 ± 3.2	5.6 ± 3.5	4.8 ± 2.7
Th8	12.4 ± 1.4	12.9 ± 1.2	11.8 ± 1.4*	5.4 ± 1.1	5.8 ± 1.1	4.9 ± 1*	42.1 ± 4.3	43.5 ± 4.6	40.5 ± 3.3*	4.4 ± 3.4	3.9 ± 3.1	4.9 ± 3.7
Th9	13.2 ± 1.3	13.6 ± 1.1	12.7 ± 1.3*	5.8 ± 1.2	6.3 ± 1.1	5.1 ± 0.9*	42 ± 4.7	43.3 ± 4.7	40.6 ± 4.3*	4.3 ± 4.5	4 ± 5.3	4.6 ± 3.3
Th10	15.4 ± 1.6	15.8 ± 1.5	14.9 ± 1.7*	6.7 ± 1.3	7.4 ± 1.1	5.9 ± 1*	43.4 ± 4.9	45.5 ± 3.8	40.8 ± 4.8*	4.7 ± 3.3	4.3 ± 3.1	5.2 ± 3.6
Th11	17.3 ± 1.6	17.8 ± 1.6	16.6 ± 1.3*	8.2 ± 1.5	8.6 ± 1.5	7.7 ± 1.4*	45 ± 5.7	47.1 ± 5.9	42 ± 3.9*	4.7 ± 4.3	4.6 ± 3.9	5 ± 4.9
Th12	17.5 ± 1.7	18.2 ± 1.7	16.6 ± 1.3*	8.4 ± 1.6	8.9 ± 1.3	7.7 ± 1.6*	47.3 ± 5.7	48.8 ± 5.7	45.1 ± 5.1*	6.1 ± 5.3	5.3 ± 3.5	7.2 ± 7.1
L1	16.1 ± 1.8	16.7 ± 1.6	14.8 ± 1.3*	7.8 ± 2	8.4 ± 1.8	6.5 ± 1.6*	52.8 ± 4.8	54.6 ± 4.1	49.1 ± 3.9*	10.8 ± 3.6	10.7 ± 3.5	11.1 ± 3.8
L2	15.2 ± 1.8	15.8 ± 1.7	14 ± 1.3*	8.2 ± 1.9	8.9 ± 1.8	6.8 ± 1.5*	53.3 ± 5	55.4 ± 4.4	49.4 ± 3.4*	11.5 ± 3.9	11.9 ± 4.2	10.6 ± 3.3*
L3	14.9 ± 1.9	15.5 ± 1.8	13.7 ± 1.5*	9.8 ± 2.3	10.7 ± 2	8.2 ± 1.8*	54.6 ± 5.1	56.5 ± 4.6	50.8 ± 3.5*	14.2 ± 3.9	14.2 ± 3.8	14 ± 4.1
L4	13.7 ± 2	14.2 ± 2	12.7 ± 1.6*	11.7 ± 2.2	12.5 ± 2	10.3 ± 1.7*	54.3 ± 4.7	56 ± 4.4	51.1 ± 3.6*	16.3 ± 4.4	16 ± 4.2	16.9 ± 4.7*
L5	12.9 ± 1.8	13.3 ± 1.8	12.1 ± 1.6*	15.6 ± 2.6	16.4 ± 2.6	14.1 ± 2.1*	52.8 ± 5	54 ± 5.1	50.5 ± 3.9*	26.1 ± 5.9	25.4 ± 5.6	27.4 ± 6.3*
LSTV	14.8 ± 1.9	14.9 ± 2	14.4 ± 1.7	16.2 ± 2.6	17.1 ± 2	14 ± 2.8*	54.3 ± 3.8	55 ± 3.6	52.9 ± 4.4	27.1 ± 5.3	26.7 ± 5.8	28.3 ± 4.6

Data are given as means and standard deviations.

* Statistically significant compared with the value for male ($P < 0.05$).

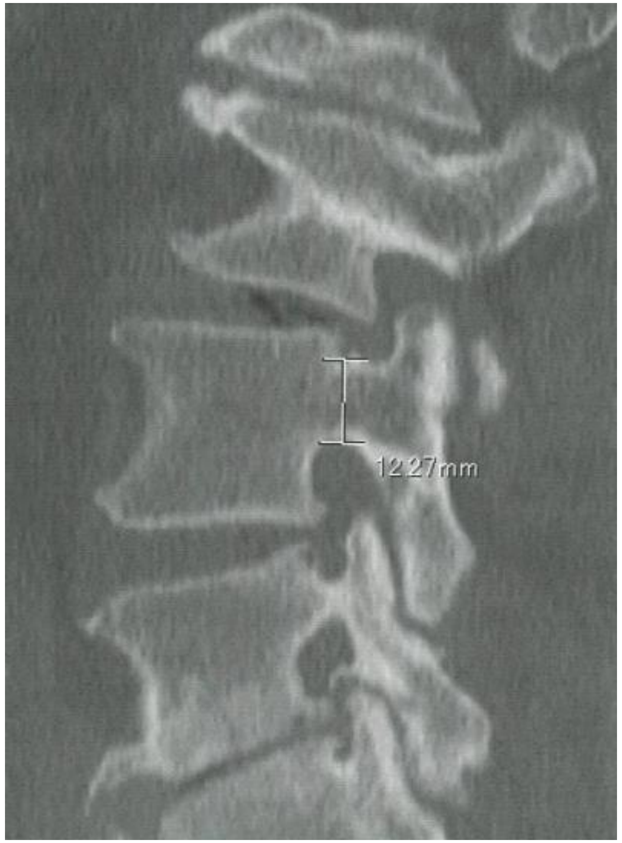
Figure. 1



(A) Pedicle Height
(B) Pedicle Width
(C) Pedicle Length
Pedicle Axis
(D) Pedicle Transverse Angle
Pedicle Transverse Angle
Pedicle Axis
Median Line

Figure. 2

(A) Pedicle Height



(B) Pedicle Width, Pedicle Length, and Pedicle Transverse Angle

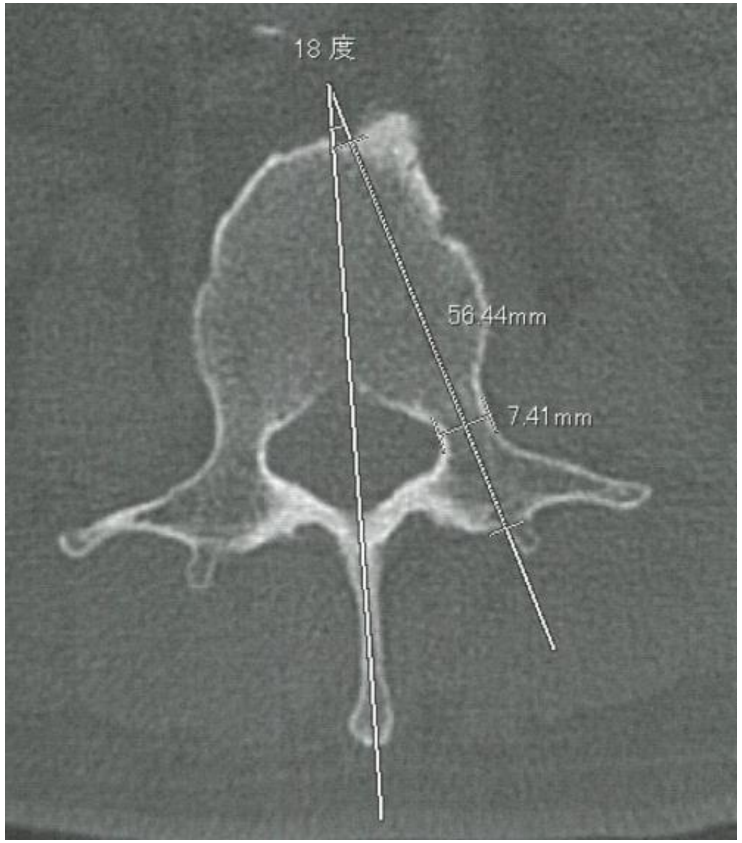


Figure. 3

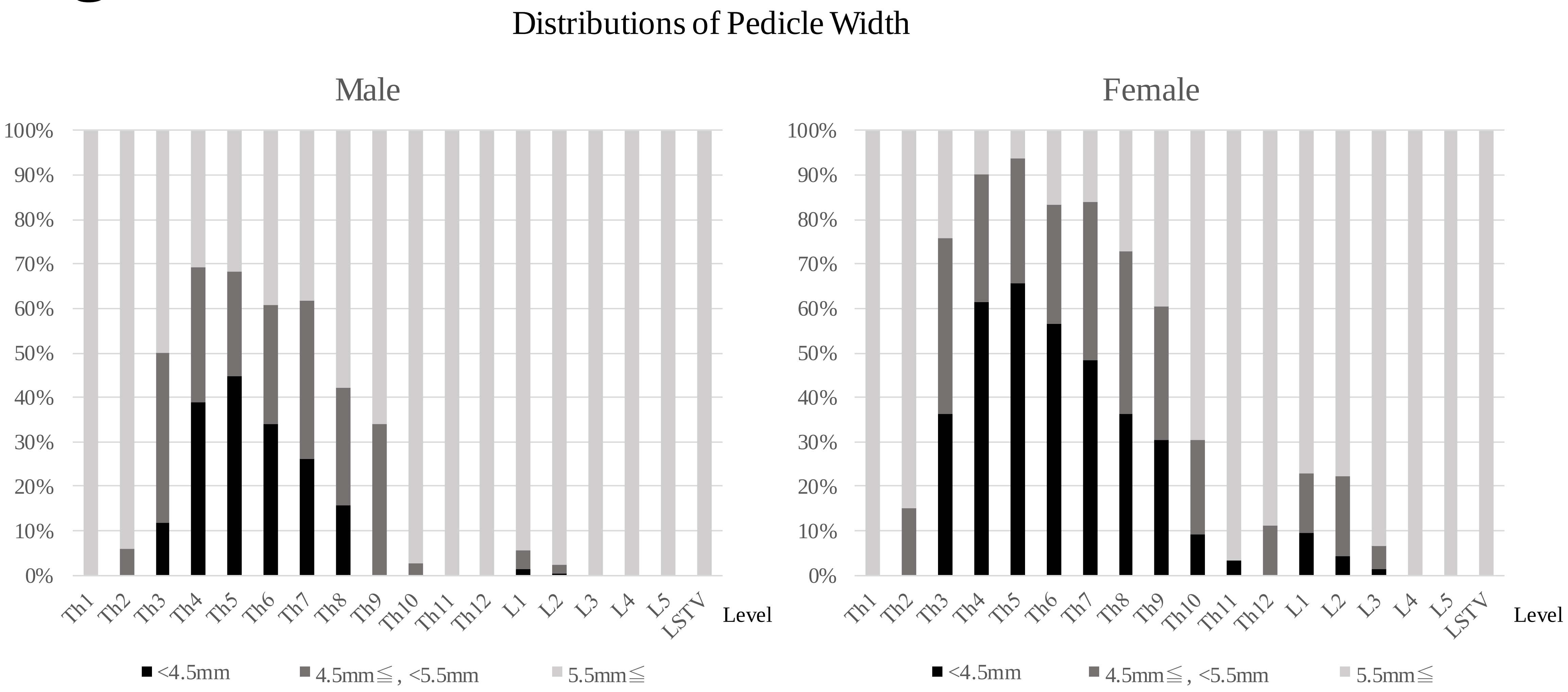

Distributions of Pedicle Width
Male
Female
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Th1 Th2 Th3 Th4 Th5 Th6 Th7 Th8 Th9 Th10 Th11 Th12 L1 L2 L3 L4 L5 LSTV
Level
<4.5mm
4.5mm≦, <5.5mm
5.5mm≦

Figure. 4

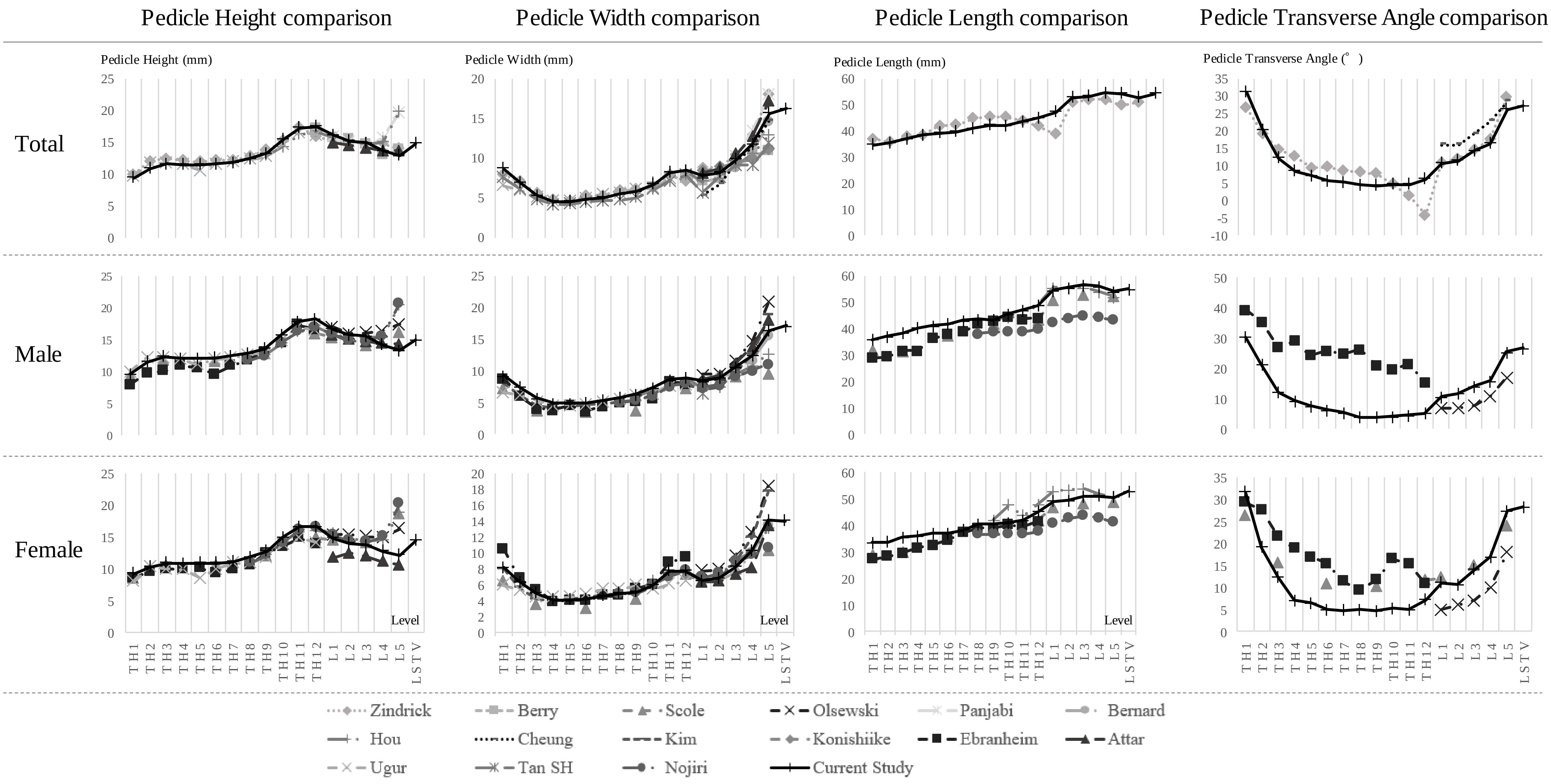
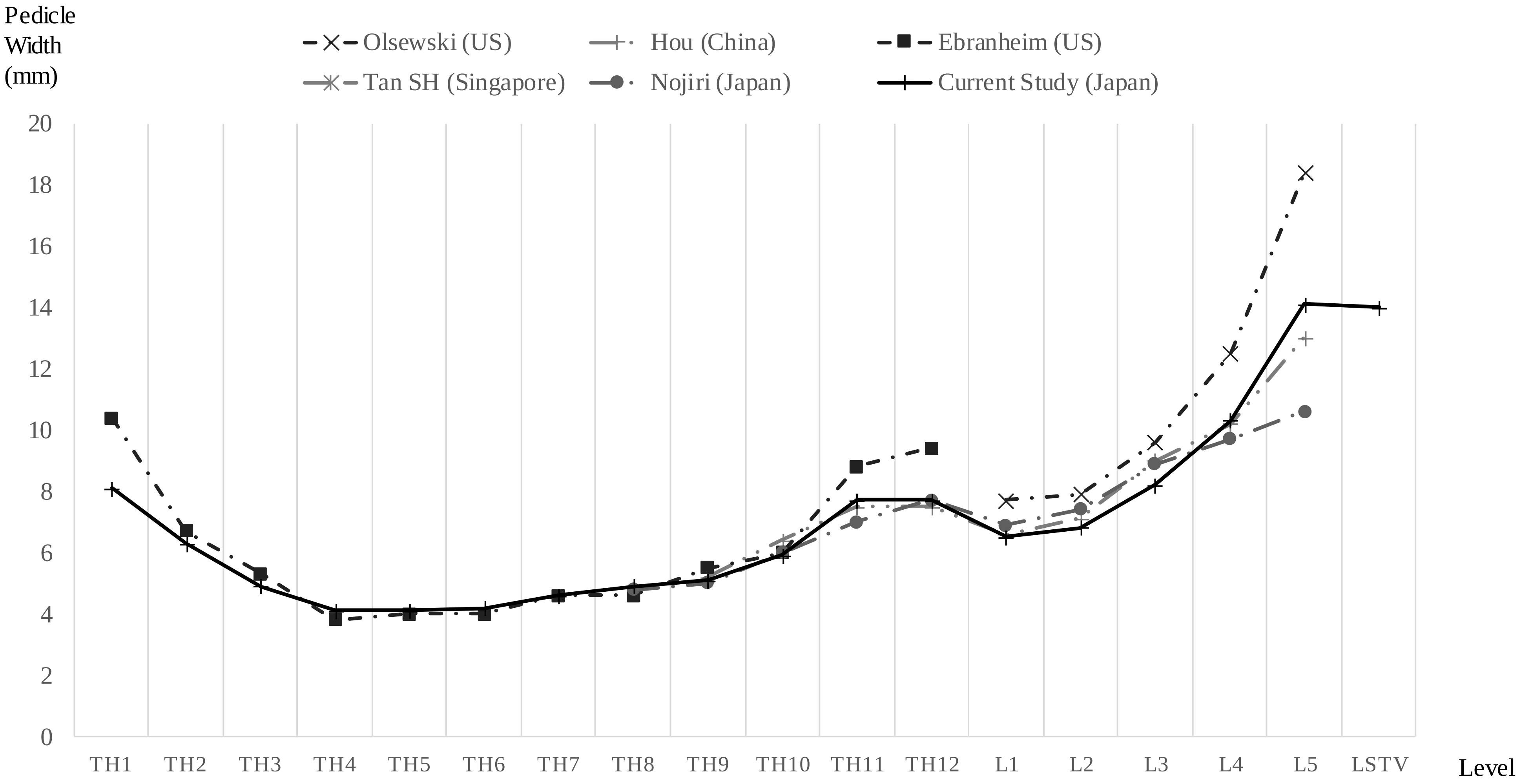

Pedicle Height comparison
Pedicle Width comparison
Pedicle Length comparison
Pedicle Transverse Angle comparison
Pedicle Height (mm)
Pedicle Width (mm)
Pedicle Length (mm)
Pedicle Transverse Angle (°)
Total
Male
Female
Level
TH1 TH2 TH3 TH4 TH5 TH6 TH7 TH8 TH9 TH10 TH11 TH12 L1 L2 L3 L4 L5 LSTV
Zindrick
Berry
Scole
Olsewski
Panjabi
Bernard
Hou
Cheung
Kim
Konishiike
Ebranheim
Attar
Ugur
Tan SH
Nojiri
Current Study

Figure. 5



Pedicle Width (mm)
Olsewski (US)
Hou (China)
Ebranheim (US)
Tan SH (Singapore)
Nojiri (Japan)
Current Study (Japan)
20
18
16
14
12
10
8
6
4
2
0
TH1
TH2
TH3
TH4
TH5
TH6
TH7
TH8
TH9
TH10
TH11
TH12
L1
L2
L3
L4
L5
LSTV
Level