Comparison of radiographic and computed tomographic measurement of pedicle and vertebral body dimensions in Koreans: the ratio of pedicle transverse diameter to vertebral body transverse diameter

Ki Ser Kang · Kwang-Sup Song · Jong Seok Lee ·
Jae Jun Yang · In Sup Song

Received: 31 May 2010 / Accepted: 14 August 2010 / Published online: 30 August 2010
© Springer-Verlag 2010

Abstract This study was designed to investigate the characteristics of pedicle transverse diameters (PD), vertebral body transverse diameters (VBD), especially the ratios of PD/VBD (CT ratio), which has never been discussed, in Koreans using computed tomography (CT) scans and to evaluate the possibility of obtaining more accurate estimations of PD from plain radiographs using the CT ratios in each spine level. The T1–L5 vertebrae of 50 participants were analyzed prospectively with CT scans (CT-VBD and CT-PD), and the T9–L5 vertebrae of the same participants were investigated with plain radiographs (X-VBD and X-PD). The CT ratio had a higher correlation with the CT-PD ($r^2 = 0.630$) from T1 to L5, especially in the lower thoracic and lumbar spine (T9–L5, $r^2 = 0.737$). The correlation of VBDs between the two radiologic tools ($r^2 = 0.896$) was higher than that of the PDs ($r^2 = 0.665$). Based on the data, equations for the estimation of a more accurate PD from plain radiographs were developed as follows: estimated PD = estimated VBD $\times$ [1.014 $\times$ (X-VBD) + 0.152] $\times$ the mean CT ratio at each spinal level. The correlation between the estimated PD and the CT-PD ($r^2 = 0.852$) was improved compared with that ($r^2 = 0.665$) between the X-PD and the CT-PD. In conclusion, the CT ratio showed a very similar changing trends to CT-PD from T1 to L5 regardless of sex and body mass,

and the measurement error of PD from only plain radiographs could be minimized using estimated VBD and the mean CT ratio at each spinal level.

Keywords Pedicle transverse diameter · Vertebral body transverse diameter · Ratio · Radiograph · Computed tomography

Introduction

Many studies have been carried out concerning the anatomical morphology of the spine pedicle for selecting adequate screw size, entrance point, and screw direction for instrumentation of the pedicle screws [1–5]. Both screw diameter and screw length are important for safe screw placement. However, it is well known that diameter is more important than length in terms of screw–bone interface strength to determine pull-out strength of pedicle screw [2].

Studies [2, 6–13] on the morphology of the thoracic and lumbar pedicles have been reported using cadaveric or radiologic measurements. Computed tomography (CT) scans, with an established accuracy for evaluating pedicle dimension, are most commonly used as the best radiologic tool for measuring various radiographic pedicle parameters [6, 14–16]. In comparison with the CT scan, it is well known that plain radiograph is a relatively inaccurate way to evaluate pedicle diameter because of various three-dimensional structures with different transverse and sagittal angles of pedicle at each spine level.

This study was designed to present the characteristics of pedicle transverse diameters (PD), vertebral body transverse diameters (VBD), and the ratios of PD/VBD of vertebrae T1–L5 in Koreans using CT scans, to evaluate the discrepancies in PD and VBD between two different

K. S. Kang · K.-S. Song (✉) · J. S. Lee · J. J. Yang
Department of Orthopedic Surgery, College of Medicine,
Chung-Ang University, Heukseok-dong, Dongjak-gu,
Seoul 224-1, Korea
e-mail: ksong70@cau.ac.kr

I. S. Song
Department of Radiology, College of Medicine, Chung-Ang
University, Seoul, Korea

imaging modalities, CT scan and radiograph, and finally, to investigate the possibility of obtaining more accurate estimations of pedicle diameters from plain radiographs using the ratios of PD/VBD from CT scans in the each lower thoracic and lumbar spine from T9 to L5.

To the best of our knowledge, there have been no reports on the characteristics of the ratio of PD/VBD formed by two different primary ossification centers of vertebra in any anatomical study. We hypothesized the following: (1) CT scan is a reliable radiologic modality to provide accurate measurements of PD and VBD, (2) VBD measured on true anteroposterior radiographs incorporates less measurement error because the shape of the vertebral body has nearly circular profile, and (3) the approximate value of a true PD could be determined using the VBD as measured on plain radiographs and the mean CT ratio of PD/VBD at each spine level.

Materials and methods

The thoracic (T1–T12) and lumbar (L1–L5) vertebrae of 50 study participants (total of 850 vertebrae) were analyzed prospectively with CT scans (LightSpeed Ultra 16, GE, WI, USA) between July 2006 and August 2007. Thoracolumbar (centered on T12) and lumbar anteroposterior (centered on L3) plain radiographs were also obtained from the same participants, and lower thoracic (T9–T12) and lumbar (L1–L5) vertebrae (total of 450 vertebrae) were analyzed. The tube–film distance was kept constant at 100 cm, and the radiographic films were marked with scales of 1 cm intervals to adjust the image magnification. The adjusted magnification values with the scales on the radiographs were calculated down to two places of decimals. The measurements of thoracic vertebrae from T1 to T8 on plain radiographs were excluded because of poor intra-observer interclass correlation coefficients (ICC, the value of $ICC < 0.6$) caused by a difficulty in delineating the outer margins of the pedicles and obtaining the true anteroposterior radiograph.

Initial applicants with abnormal vertebrae ($n = 6$), including previous fractures ($n = 2$), a history of spine surgery ($n = 1$), and scoliosis ($n = 3$, $>10^\circ$ of Cobb angle), were excluded from this study. The study subjects were recruited on a voluntary basis, and all subjects signed an informed consent that was reviewed and accepted by the hospital ethics committee.

The mean age of the participants was 39.8 years (range 19–51 years), with the mean age of 35 male participants being 35.8 years (range 19–47 years) and the mean age of 15 female participants being 41 years (range 23–51 years). The mean height and bodyweight of the

male subjects were 170.6 cm (range 182–159 cm) and 70.5 kg (range 84–59 kg), while those for the female subjects were 161.2 cm (range 169–152 cm) and 53.4 kg (range 72–48 kg), respectively.

The axial images at the mid-pedicle level of each vertebra on the sagittal scout view from T1 to L5 with a 1-mm cut on the CT scan were made parallel to the vertebral superior endplates. The three consecutive mid-pedicle axial cuts at each vertebra were chosen for the selection of standard axial image, and this process was carried out by a radiologist (S.I.S) with 15 years of experience in a musculoskeletal radiology. Lower thoracic and lumbar anteroposterior plain radiographs were taken with the patient in a supine position with knees flexed in order to flatten the lumbar lordosis. The measurements of the pedicle and vertebral body diameters were performed with vernier calipers (resolution of 0.1 mm) to measure the distance between the outer cortices on developed CT and plain radiographic images. An observer with 7 years of experience in a spine surgery (L.J.S) measured all of the data twice.

Measurements on CT scans from T1 to S1

Standard axial section

The standard axial section was defined as the plane parallel to the superior end plate of the vertebral body where the width of both pedicles was largest among three axial images (Fig. 1).

Anteroposterior axis (line A)

The anteroposterior axis (line A) was defined as the line that bisected the vertebral body and vertebral foramen on a 1×1 mm grid-patterned overlay (Fig. 1).

Measurement of VBD and PD

A line (line B, Fig. 1) was drawn perpendicular to the anteroposterior axis (line A) and tangential to the outer cortical margin of the most anterior projection of the vertebral foramen. VBD was measured on the anterior side of this line, and the PD was measured on its posterior side.

Vertebral body transverse diameter (CT-VBD) The VBD was defined as the longest distance between the bilateral outer cortices of the vertebral body in a line perpendicular to the anteroposterior axis (C, Fig. 1). The superior costal facet of the thoracic vertebrae was ignored, and the VBD was measured on the smooth margin made by drawing an imaginary line (line E, Fig. 1b) from the vertebral body on line B.

Fig. 1 Axial image of lumbar vertebra (a) and thoracic vertebra (b) on CT scans: *line A* anteroposterior axis; *line B* perpendicular to the *line A* at the most anterior projection of the vertebral foramen. *C* vertebral body transverse diameter, *D* pedicle transverse diameter, and *line E* an imaginary line from the thoracic vertebral body

Pedicle transverse diameter (CT-PD) The shortest distance between the outer cortices of the pedicle on a 1×1 mm grid-patterned overlay was measured in both the right and left pedicles (D, Fig. 1). The PD was defined as the shorter of these two measurements.

The ratio of PD/VBD (CT ratio) The PD/VBD ratio was calculated mathematically and presented as a percentage.

Measurements on plain radiographs from T9 to L5

Standard axial line (line A)

Lower thoracic and lumbar true anteroposterior plain radiographs were obtained with a spinous process reference (Fig. 2). The standard axial line (i.e., the mid-pedicle line) was defined as a transverse line where the diameters of both pedicles were largest.

Fig. 2 An anteroposterior plain radiograph of the lumbar vertebrae. *Line A* standard axial line (mid-pedicle line), *B* vertebral body transverse diameter, and *C* pedicle transverse diameter

Measurement of VBD and PD (X-VBD and X-PD)

The VBD was defined as the distance between the bilateral outer cortices of the vertebral body on the standard axial line in an anteroposterior radiograph (B, Fig. 2). The PD was defined as the shorter line between the right and left pedicle diameters as measured on the standard axial line (C, Fig. 2).

Statistical analyses

All statistical analyses were performed with SPSS® version 15.0. Differences between male and female subjects were compared with two-tailed Student's *t* tests at a significance level of $p < 0.05$. Pearson's correlation analysis and linear regression analysis were employed to investigate the relationships of the PDs and VBDs determined by the two imaging methods and the ratios (PD/VBD) and PDs or VBDs as determined by CT scans. The intra-observer correlation was evaluated using the interclass correlation coefficient (ICC).

Results

All intra-observer ICCs for CT-PDs, CT-VBDs, X-PDs, and X-VBDs were over 0.92. The male subjects had larger bodyweights and greater heights than the female subjects ($p < 0.05$).

Measurements on CT scan

Vertebral body transverse diameter and pedicle transverse diameter

The average CT-VBD was smallest at T4 (mean $\pm$ SD 26.97 ± 2.69 mm) and largest at L5 (mean $\pm$ SD

Table 1 Pedicle transverse diameter and vertebral body transverse diameter (mean $\pm$ SD, mm)

Level	CT scan						Plain radiograph	
	Pedicle			Vertebral body			Pedicle	Vertebral body
	Male (n = 35)	Female (n = 15)	Total (n = 50)	Male (n = 35)	Female (n = 15)	Total (n = 50)	(n = 50)	(n = 50)
T1	8.08 $\pm$ 1.41	7.32 $\pm$ 1.78	7.85 $\pm$ 1.55	30.46 $\pm$ 3.05	28.31 $\pm$ 3.67	29.82 $\pm$ 3.36		
T2	6.96 $\pm$ 1.06	6.39 $\pm$ 1.70	6.79 $\pm$ 1.30	29.92 $\pm$ 2.19	27.93 $\pm$ 2.90	29.32 $\pm$ 2.56		
T3	5.89 $\pm$ 1.09	5.57 $\pm$ 1.44	5.79 $\pm$ 1.20	28.29 $\pm$ 2.59	25.71 $\pm$ 2.80	27.52 $\pm$ 2.89		
T4	5.38 $\pm$ 0.93	4.83 $\pm$ 1.02	5.21 $\pm$ 0.98	27.94 $\pm$ 2.37	24.71 $\pm$ 1.94	26.97 $\pm$ 2.69		
T5	5.62 $\pm$ 0.99*	4.75 $\pm$ 0.83	5.36 $\pm$ 1.02	28.73 $\pm$ 2.52	24.98 $\pm$ 1.87	27.60 $\pm$ 2.90		
T6	5.86 $\pm$ 1.12*	5.11 $\pm$ 1.06	5.61 $\pm$ 1.14	29.29 $\pm$ 2.12	25.61 $\pm$ 1.63	28.18 $\pm$ 2.61		
T7	5.88 $\pm$ 1.42*	4.99 $\pm$ 1.18	5.64 $\pm$ 1.40	30.27 $\pm$ 2.20	26.93 $\pm$ 2.00	29.27 $\pm$ 2.63		
T8	6.01 $\pm$ 1.09	5.37 $\pm$ 1.20	5.82 $\pm$ 1.15	31.41 $\pm$ 2.32	27.69 $\pm$ 1.84	30.29 $\pm$ 2.77		
T9	6.54 $\pm$ 1.05*	5.65 $\pm$ 0.98	6.27 $\pm$ 1.10	32.21 $\pm$ 2.19	28.25 $\pm$ 2.02	31.02 $\pm$ 2.80	6.76 $\pm$ 1.04	30.60 $\pm$ 2.50
T10	7.27 $\pm$ 1.52	6.53 $\pm$ 0.96	7.05 $\pm$ 1.41	34.31 $\pm$ 2.65	30.19 $\pm$ 2.44	33.07 $\pm$ 3.19	7.44 $\pm$ 1.41	33.01 $\pm$ 3.14
T11	9.15 $\pm$ 1.93*	7.27 $\pm$ 1.16	8.58 $\pm$ 1.93	38.57 $\pm$ 4.46	32.91 $\pm$ 3.03	36.87 $\pm$ 4.83	8.23 $\pm$ 1.35	37.00 $\pm$ 4.02
T12	9.64 $\pm$ 1.83*	7.95 $\pm$ 0.87	9.13 $\pm$ 1.77	40.77 $\pm$ 2.58	35.53 $\pm$ 2.61	39.20 $\pm$ 3.53	8.18 $\pm$ 1.42	39.37 $\pm$ 3.59
L1	8.61 $\pm$ 1.80*	7.13 $\pm$ 1.25	8.16 $\pm$ 1.78	41.98 $\pm$ 2.80	35.55 $\pm$ 2.19	40.05 $\pm$ 3.96	7.09 $\pm$ 1.40	38.76 $\pm$ 4.15
L2	8.95 $\pm$ 1.42*	7.62 $\pm$ 1.55	8.55 $\pm$ 1.57	43.80 $\pm$ 2.96	37.30 $\pm$ 2.58	41.85 $\pm$ 4.13	7.52 $\pm$ 1.40	40.64 $\pm$ 4.28
L3	10.63 $\pm$ 1.70*	8.78 $\pm$ 1.12	10.08 $\pm$ 1.76	46.31 $\pm$ 3.44	40.71 $\pm$ 2.70	44.63 $\pm$ 4.12	8.82 $\pm$ 1.44	44.29 $\pm$ 4.19
L4	12.14 $\pm$ 2.03*	10.19 $\pm$ 1.50	11.55 $\pm$ 2.07	48.06 $\pm$ 3.37	43.77 $\pm$ 3.30	46.77 $\pm$ 3.86	10.01 $\pm$ 1.84	45.51 $\pm$ 4.31
L5	17.08 $\pm$ 2.23*	15.23 $\pm$ 2.43	16.53 $\pm$ 2.42	54.83 $\pm$ 4.31	49.72 $\pm$ 4.59	53.30 $\pm$ 4.95	11.89 $\pm$ 2.03	51.33 $\pm$ 3.81

* Significant difference of pedicle transverse diameter between male and female ($p < 0.05$)

53.30 $\pm$ 4.95 mm) (Table 1). The average CT-VBD gradually decreased from T1 to T4 and increased from T5 to L5.

The average CT-PD was smallest at T4 (mean $\pm$ SD 5.21 $\pm$ 0.98 mm) and largest at L5 (mean $\pm$ SD 16.53 $\pm$ 2.42 mm). The average CT-PD gradually decreased from T1 to T4 and increased from T4 to L5 except for the spine level from T12 to L1. The mean CT-PDs at L1 were smaller than those at T12 ($p < 0.001$). The finding that the average CT-PD decreased from T12 to L1 was observed in all male and female subject groups. Male subjects had larger mean CT-PDs than did female subjects at all spine levels, and the differences were statistically significant at the spine levels from T5 to L5 except for T8 and T10 ($p < 0.05$).

The ratio of PD/VBD (CT ratio)

The lowest CT ratio was observed at T7 (mean $\pm$ SD 19.14 $\pm$ 4.2%), and the highest ratio was at L5 (mean $\pm$ SD 31.13 $\pm$ 4.54%) (Table 2). The distribution of the CT ratios was as follows: the values of the vertebrae from T4 to T8 were below 20%, and T3, T9, T10, and L2 ranged from 20 to 22%, while T2, T11, T12, L3, and L4 ranged from 22 to 25% and T1 and L5 were over 25%. The mean CT ratio gradually decreased from T1 to T4 and primarily increased from T5 to L5 except at the levels of

Table 2 Ratio of pedicle transverse diameter to vertebral body transverse diameter (mean $\pm$ SD, %)

Level	CT scan		
	Male (n = 35)	Female (n = 15)	Total (n = 50)
T1	26.65 $\pm$ 4.50	25.79 $\pm$ 5.35	26.39 $\pm$ 4.73
T2	23.26 $\pm$ 3.11	22.72 $\pm$ 4.69	23.10 $\pm$ 3.62
T3	20.83 $\pm$ 3.40	21.51 $\pm$ 3.80	21.03 $\pm$ 3.50
T4	19.31 $\pm$ 3.31	19.64 $\pm$ 4.27	19.41 $\pm$ 3.58
T5	19.65 $\pm$ 3.50	19.04 $\pm$ 3.25	19.46 $\pm$ 3.41
T6	19.99 $\pm$ 3.33	19.95 $\pm$ 3.61	19.98 $\pm$ 3.38
T7	19.38 $\pm$ 4.12	18.58 $\pm$ 4.32	19.14 $\pm$ 4.16
T8	19.16 $\pm$ 3.52	19.42 $\pm$ 4.10	19.23 $\pm$ 3.66
T9	20.38 $\pm$ 3.56	20.06 $\pm$ 3.46	20.29 $\pm$ 3.50
T10	21.22 $\pm$ 4.33	21.57 $\pm$ 2.08	21.32 $\pm$ 3.78
T11	24.02 $\pm$ 5.38	22.25 $\pm$ 3.98	23.49 $\pm$ 5.03
T12	23.69 $\pm$ 4.62	22.43 $\pm$ 2.40	23.31 $\pm$ 4.10
L1	20.51 $\pm$ 4.15	20.02 $\pm$ 3.05	20.36 $\pm$ 3.83
L2	20.48 $\pm$ 3.22	20.42 $\pm$ 3.75	20.46 $\pm$ 3.35
L3	22.97 $\pm$ 3.30	21.63 $\pm$ 2.81	22.57 $\pm$ 3.19
L4	25.28 $\pm$ 3.98	23.37 $\pm$ 3.63	24.71 $\pm$ 3.94
L5	31.32 $\pm$ 4.54	30.71 $\pm$ 4.66	31.13 $\pm$ 4.54

T6–T7, T11–T12, and T12–L1. The mean CT ratio of L1 was smaller than that of T12 ($p < 0.001$), which was similar to the pattern of the CT-PD of T12 and L1. There

was no significant difference between male and female subjects in the mean ratios of all spinal levels ($p > 0.05$).

Correlation between the CT ratio and other parameters

The CT-ratio curve had a more similar shape to the CT-PD curve than to the CT-VBD curve from T1 to L5 (CT-PD: $r^2 = 0.630$, CT-VBD: $r^2 = 0.118$), especially in the lower thoracic and lumbar vertebral levels from T9 to L5 (CT-PD: $r^2 = 0.737$, CT-VBD: $r^2 = 0.136$) (Fig. 3).

Measurements on plain radiographs (from T9 to L5)

The average X-VBD was smallest at T9 (mean $\pm$ SD 30.60 ± 2.50 mm) and largest at L5 (mean $\pm$ SD $51.33 \pm$

3.81 mm) (Table 1). The X-VBD gradually increased from T9 to L5, except for the levels from T12 to L1.

The average X-PD was smallest at T9 (mean $\pm$ SD 6.76 ± 1.04 mm) and largest at L5 (mean $\pm$ SD 11.89 ± 2.03 mm). The X-PD gradually increased from T9 to L5 except the levels from T11 to L1, and the mean X-PD of L1 was smaller than that of T12 ($p < 0.001$).

Comparison of measurements between CT scans and plain radiographs

The correlation of VBDs ($r^2 = 0.896$) between measurements on CT scans and plain radiographs was higher than that of PDs ($r^2 = 0.665$) from T9 to L5 (Fig. 4).

Fig. 3 a The mean CT-VBD, CT-PD, and the ratio (PD/VBD $\times$ 100) for T1–L5 are illustrated on a linear graph. b The CT-ratio curve is more similar to the CT-PD ($r^2 = 0.737$) curve than the CT-VBD ($r^2 = 0.136$) curve, especially along vertebral levels of T9–L5

Fig. 4 The linear regression graphs of CT-VBD and X-VBD, and CT-PD and X-PD. The correlation of VBDs ($r^2 = 0.896$) was higher than that of PDs ($r^2 = 0.665$). The equation of the least-squares regression line in the CT-VBD/X-VBD graph is $Y = 1.014X + 0.152$

Estimation of true pedicle diameters
from the measurements of VBD on plain radiographs

If the above result (“[Comparison of measurements between CT scans and plain radiographs](#)”) satisfies our hypothesis, “VBD measured on radiographs incorporates less measurement error”, the equations were developed based on the diagram in Fig. 5 as follows:

1. Estimated VBD = $1.014X + 0.152$ (the equation of the least-squares regression line; X X-VBD; Fig. 4)
2. Estimated PD = estimated VBD $\times$ the average CT ratio at each spinal level.
3. The final equation is as follows:

Estimated PD = $(1.014 \times X\text{-VBD} + 0.152) \times$ the average CT ratio at each spinal level (Table 2).

Fig. 5 A schematic diagram estimating accurate pedicle transverse diameter using estimated VBD and the mean CT ratio at each spinal level

Estimated PD compared to CT-PD and X-PD
from T9 to L5

The correlation between the estimated PD and the CT-PD ($r^2 = 0.852$) was higher than the correlation between the X-PD and the CT-PD ($r^2 = 0.665$) (Fig. 6).

Discussion

Many pedicle diameter studies have been conducted using either direct measurement of human cadaver spines [7, 9, 11, 17, 18], indirect radiologic measurements [6, 8, 12, 14, 15] or combined cadaveric and radiologic measurements [2–4, 10–13, 19–21]. Most studies using both cadaveric and radiologic measurement have reported no significant difference in pedicle diameters between the two measurement schemes [2–4, 10, 13, 20]. Based on these previous reports, we considered the measurements on CT scans to be the true values of the pedicle.

The PD of the thoracic and lumbar spine on CT scans from the present study has been compared with previously reported data in the literature (Fig. 7) [2, 5, 6, 13, 17]. Compared with the results reported by Kim et al. [17] in their cadaveric study, the mean diameter in our study was larger at all spinal levels except at T1, L4, and L5.

The findings that the pedicle transverse diameter at L1 was less than that at T12 is similar to the results in the studies by Kim et al. [17], Hou et al. [9], Chanda et al. [14], and Berry et al. [7]; however, the results differ from the report of Zindrick et al. [13]. With regard to VBD, the findings that the trend in the change of mean CT-VBD from T1 to S1, which gradually decreased from T1 to T4

Fig. 6 The linear regression graphs show a higher correlation between the estimated PD and the CT-PD ($r^2 = 0.852$) than that between the X-PD and the CT-PD ($r^2 = 0.665$)

Fig. 7 The pedicle transverse diameters of the thoracic and lumbar spine on CT scans from the present study were compared with the data from previous studies. Only the study of Zindrick et al. showed that the mean pedicle transverse diameter at L1 was larger than that at T12

and increased from T5 to S1, are similar to that of CT-PD except that the finding of decreased diameter from T12 to L1 on CT-PD was not observed.

The CT ratio is a unique radiologic parameter presented in the current study. The significant correlation ($r^2 = 0.630$) from T1 to L5, especially in vertebral levels from T9 to L5 ($r^2 = 0.737$) between the CT ratio and the CT-PD compared with the correlation ($r^2 = 0.118$) between the CT ratio and the CT-VBD, suggests that the mean CT ratio could be a useful parameter to represent the characteristics of the pedicle diameters. Furthermore, the fact that there is no significant difference between males and females in the CT ratios at each spinal level implies that the CT ratio is a

consistent parameter along the thoracic and lumbar spine, regardless of sex and body mass.

In terms of development of spine, vertebral body is formed by two ossification center: one in the center of the centrum and one in each of the vertebral arch halves. The latter ossification center participates in the formation at pedicle as well as some vertebral diameter because neo-central joints are located anterior to the site of the future pedicle [22]. The results that the CT ratio (PD/VBD) had a similar trend and higher correlation to the CT-PD ($r^2 = 0.630$) than that of CT-VBD ($r^2 = 0.118$) from T1 to L5 and the correlation between inverse CT-VBD and CT-PD was $r^2 = 0.079$ (not shown data) from T1 to L5 could suggest the possibility that the change VBDs including PDs from T1 to L5 would be more influenced by ossification center in vertebral arch. The above data for CT ratios might be useful backup data for developmental anatomic study particularly if future studies show it to be highly reliable in multiple racial and ethnic groups and over a large range of body sizes.

In comparisons between the plain radiographs and CT scans in the lower thoracic and lumbar spinal levels (from T9 to L5), the X-VBD showed accurate measurements with high correlation ($r^2 = 0.896$) compared to the CT-VBD, which satisfies our second hypothesis that the nearly circular profile of vertebral bodies decreases the measurement error on plain radiographs. The X-PDs measured from T9 to L5 were significantly smaller ($p < 0.05$) than the CT-PDs at all levels except T9 and T10. The underestimation of the pedicle diameter in plain radiographs is thought to result from the fact that the maximum radiologic density of the pedicle is well within the true cortical margin of the pedicle due to complex transverse and sagittal pedicle angles at each spinal level [12].

We made an effort to minimize the error in direct measurement of the pedicle diameter on plain radiographs and noticed two factors when reviewing the correlation of radiological parameters on CT scans and those of plain radiographs: (1) the correlation between the CT-VBD and the X-VBD ($r^2 = 0.896$) was much higher than that between the CT-PD and the X-PD ($r^2 = 0.665$); the X-VBD was noted to be reliable parameter; (2) the CT-ratio curve in the lower thoracic and lumbar spine (T9–L5) showed a nearly similar pattern to the CT-PD curve with high correlation ($r^2 = 0.737$), indicating that the CT ratio is a good adjustment factor for the estimation of the pedicle diameter at that spinal level; based on the above facts, a diagram, shown in Fig. 5, was developed to estimate the pedicle diameter from the measurements on plain radiographs. The correlation between the estimated PD and the CT-PD ($r^2 = 0.852$) improved compared with that between the X-PD and the CT-PD ($r^2 = 0.665$), which represents the increased accuracy of radiographic measurement of PD using the mean CT ratio at each spinal level (Fig. 6).

We evaluated the characteristics and differences of the plain radiographic and computed tomographic measurement of PD and VBD and presented the characteristics of CT ratio in Koreans as a radiologic anatomical study.

Moreover, the potential clinical importance of this study is that it has some potential clinical importance by possibly providing a better means for predicting pedicle width from spine radiographs.

In conclusion, the relatively accurate VBD (estimated VBD) was measured on plain radiographs, and the CT ratio consistently represented the characteristics of CT-PD in that the CT ratio showed a nearly identical pattern to the CT-PD curve. Furthermore, the CT ratio was not influenced by gender or body mass. Using the above findings, the measurement error of pedicle diameters from only plain radiographs would be minimized through the use of estimated VBD, which can be measured accurately on plain radiograph, and the mean CT ratio at each spinal level.

Acknowledgments This research was supported by the Chung-Ang University Research Grants in 2010.

References

- King D (1948) Internal fixation for lumbosacral fusion. *J Bone Joint Surg* 30A:560–565
- Krag MH, Weaver DL, Beynnon BD, Haugh LD (1988) Morphometry of the thoracic and lumbar spine related to transpedicular screw placement for surgical spinal fixation. *Spine* 13:27–32
- Misenhimer GR, Peek RD, Wiltse LL, Rothman SL, Widell EH Jr (1989) Anatomic analysis of pedicle cortical and cancellous diameter as related to screw size. *Spine* 14:367–372
- Olsewski JM, Simmons EH, Kallen FC, Mendel FC, Severin CM, Berens DL (1990) Morphometry of the lumbar spine: anatomical perspectives related to transpedicular fixation. *J Bone Joint Surg* 72:541–549
- Yahiro MA (1994) Comprehensive literature review. Pedicle screw fixation devices. *Spine* 19:2274S–2278S
- Bernard TN Jr, Seibert CE (1992) Pedicle diameter determined by computed tomography. Its relevance to pedicle screw fixation in the lumbar spine. *Spine* 17:S160–S163
- Berry JL, Moran JM, Berg WS, Steffee AD (1987) A morphometric study of human lumbar and selected thoracic vertebrae. *Spine* 12:362–367
- Cheung KM, Ruan D, Chan FL, Fang D (1994) Computed tomographic osteometry of Asian lumbar pedicles. *Spine* 19:1495–1498
- Hou S, Hu R, Shi Y (1993) Pedicle morphology of the lower thoracic and lumbar spine in a Chinese population. *Spine* 18:1850–1855
- Marchesi D, Schneider E, Glauser P, Aebi M (1988) Morphometric analysis of the thoracolumbar and lumbar pedicles, anatomic-radiologic study. *Surg Radiol Anat* 10:317–322
- Panjabi MM, Goel V, Oxland T, Takata K, Duranceau J, Krag M, Price M (1992) Human lumbar vertebrae. Quantitative three-dimensional anatomy. *Spine* 17:299–306
- Robertson PA, Stewart NR (2000) The radiologic anatomy of the lumbar and lumbosacral pedicles. *Spine* 25:709–715
- Zindrick MR, Wiltse LL, Doornik A, Widell EH, Knight GW, Patwardhan AG, Thomas JC, Rothman SL, Fields BT (1987) Analysis of the morphometric characteristics of the thoracic and lumbar pedicles. *Spine* 12:160–166
- Chadha M, Balain B, Maini L, Dhaon BK (2003) Pedicle morphology of the lower thoracic, lumbar, and S1 vertebrae: an Indian perspective. *Spine* 28:744–749
- Krag MH, Beynnon BD, Pope MH, Frymoyer JW, Haugh LD, Weaver DL (1986) An internal fixator for posterior application to short segments of the thoracic, lumbar, or lumbosacral spine. Design and testing. *Clin Orthop Relat Res* 203:75–98
- Zindrick MR, Wiltse LL, Widell EH, Thomas JC, Holland WR, Field BT, Spencer CW (1986) A biomechanical study of intrapeduncular screw fixation in the lumbosacral spine. *Clin Orthop Relat Res* 203:99–112
- Kim NH, Lee HM, Chung IH, Kim HJ, Kim SJ (1994) Morphometric study of the pedicles of thoracic and lumbar vertebrae in Koreans. *Spine* 19:1390–1394
- McLain RF, Ferrara L, Kabins M (2002) Pedicle morphometry in the upper thoracic spine: limits to safe screw placement in older patients. *Spine* 27:2467–2471
- Datir SP, Mitra SR (2004) Morphometric study of the thoracic vertebral pedicle in an Indian population. *Spine* 29:1174–1181
- Mitra SR, Datir SP, Jadhav SO (2002) Morphometric study of the lumbar pedicle in the Indian population as related to pedicular screw fixation. *Spine* 27:453–459
- van Schaik JJ, Verbiest H, van Schaik FD (1985) Morphometry of lower lumbar vertebrae as seen on CT scans: newly recognized characteristics. *AJR* 145:327–335
- Ursu TR, Porter RW, Navaratnam V (1996) Development of the lumbar and sacral vertebral canal in utero. *Spine* 21:2705–2708