Eur Spine J (2001) 10 : 10–15
DOI 10.1007/s005860000198

ORIGINAL ARTICLE

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Lumbar pedicle: surgical anatomic evaluation and relationships

Received: 27 January 2000
Revised: 4 July 2000
Accepted: 10 July 2000
Published online: 18 October 2000

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Abstract Although several clinical applications of transpedicular screw fixation in the lumbar spine have been documented for many years, few anatomic studies concerning the lumbar pedicle and adjacent neural structures have been published. The lumbar pedicle and its relationships to adjacent neural structures were investigated through an anatomic study. Our objective is to highlight important considerations in performing transpedicular screw fixation in the lumbar spine. Twenty cadavers were used for observation of the lumbar pedicle and its relations. After removal of whole posterior bony elements including spinous processes, laminae, lateral masses, and inferior and superior facets, the isthmus of the pedicle was exposed. Pedicle width and height (PW and PH), interpedicular distance (IPD), pedicle-inferior nerve root distance (PIRD), pedicle-superior nerve root distance (PSRD), pedicle-dural sac distance (PDSD), root exit angle (REA), and nerve root diameter (NRD) were measured. The results indicated that the average distance from the lumbar pedicle to the adjacent nerve roots superiorly, inferiorly and to the dural sac medially at all levels ranged from 2.9 to 6.2 mm, 0.8 to 2.8 mm, and 0.9 to 2.1 mm, respectively. The mean PH and PW at L1–L5 ranged from 10.4 to 18.2 mm and 5.9 to 23.8 mm, respectively. The IPD gradually increased from L1 to L5. The mean REA increased consistently from 35° to 39°. The NRD was between 3.3 and 3.9 mm. Levels of significance were shown for the $P<0.05$ and $P<0.01$ levels. On the basis of this study, we can say that improper placement of the pedicle screw medially and inferiorly should be avoided.

Key words Anatomy · Cadaver · Lumbar pedicle · Transpedicular fixation

Introduction

Transpedicular screw fixation can be used for the treatment of unstable lumbar spine caused by trauma, tumors, infections, and degenerative conditions. Instrumentation techniques of the spine using the pedicle from posterior into the vertebral body have become popular recently, because of the advantages of these systems [1, 3, 4, 5, 6, 10, 11, 12,13]. Pedicle screw placement does not pose the same high risk of damage to the spinal cord, dural sac, and nerve roots in the lumbar region as it does in thoracic and cervical spine. However, accurate anatomic knowledge is needed to perform a safe surgical intervention in the lumbar region [2, 9,11]. Despite the growing interest in pedicle instrumentation in the lumbar spine, the anatomic relationships of lumbar pedicle have not yet been analyzed adequately for the safe performance of these clinical applications. Even though some of the measurements duplicate previous studies, and the data presented in this study are limited to the surrounding tissues of the pedicle, we consider such that information is necessary for building

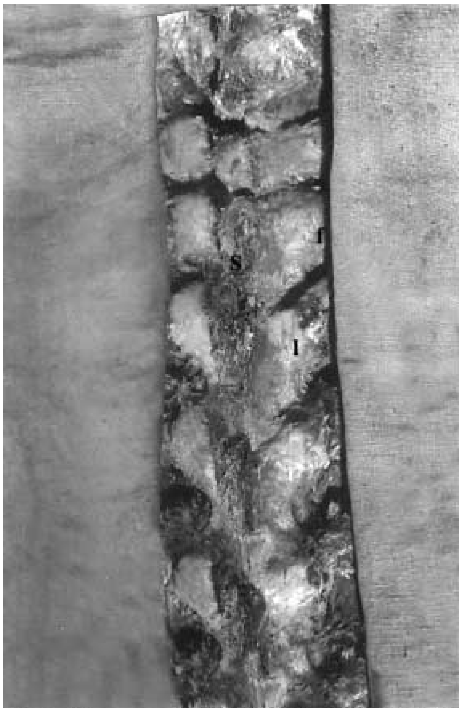

Fig. 1 View of the lumbar region after removal of all soft tissue from vertebrae, showing the spinous process (*s*), lamina (*l*), and facet joint (*f*)

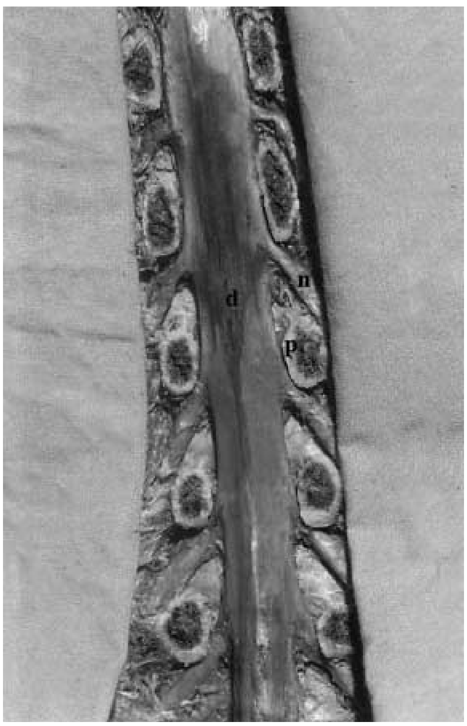

Fig. 2 View of pedicle (*p*), nerve root (*n*), and dural sac (*d*)

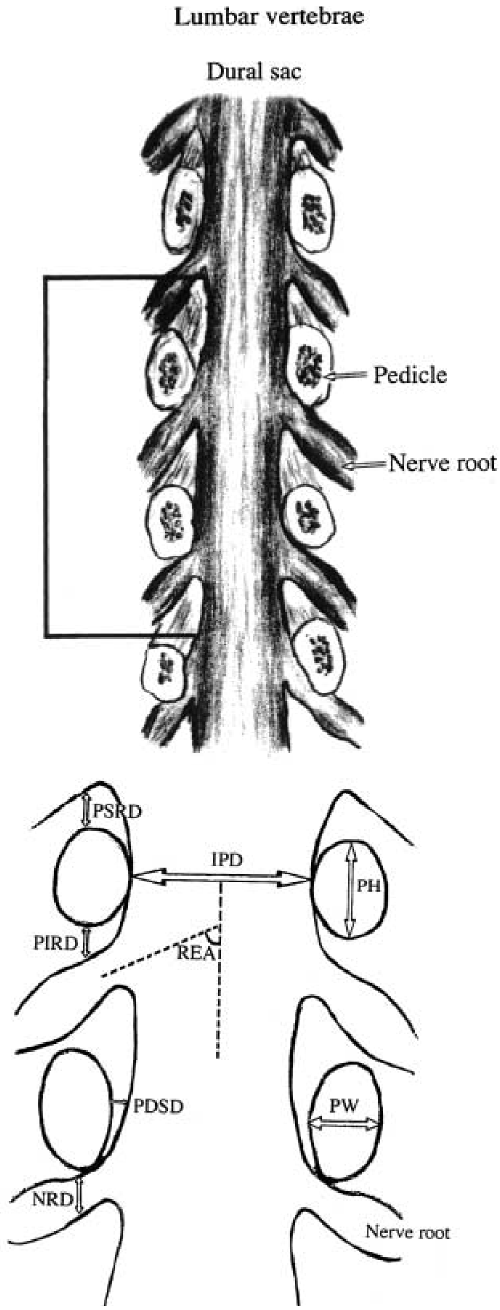

Fig. 3 Schematic drawing indicating the measurements: pedicle width (*PW*), pedicle height (*PH*) interpedicular distance (*IPD*), pedicle-inferior nerve root distance (*PIRD*), pedicle-superior nerve root distance (*PSRD*), pedicle-dural sac distance (*PDSD*), root exit angle (*REA*) nerve root diameter (*NRD*)

an anatomic data pool. The main purpose of the current study is to document the lumbar pedicle anatomy and to provide three-dimensional orientation, while emphasizing the risks involved in performing transpedicular fixation in the lumbar spine.

Material and methods

Twenty cadavers aged 29–78 years (13 men, 7 women), from the Department of Anatomy, were used for current study of the lumbar pedicle and adjacent relations. Specimens with gross deformities, such as scoliosis or kyphosis, were excluded from this study. The cadavers were placed in the prone position. Each specimen was prepared by complete removal of all soft tissue from the vertebrae (Fig. 1). A laminar ronguer and kerrison were used to remove the spinous processes, laminae, lateral masses, and superior and inferior facets. Thus, lumbar pedicle was exposed and microdissections were performed until the isthmus, which is the most narrow pedicle diameter, was exposed (Fig. 2). All dissections and measurements were performed by two experienced neurosurgeons and two experienced anatomists (A.A., H.C.U., A.U., I.T.). They reached a consensus decision on each appropriate measuring site for every parameter and the accuracy of measurements. The linear measurements were obtained using electronic digital calipers, accurate to 0.1 mm, and angular measurements were recorded with a goniometer accurate to 1°. The measurements are listed below (Fig. 3):

1. Pedicle width (PW) at isthmus
2. Pedicle height (PH) at isthmus
3. Interpedicular distance (IPD)
4. Pedicle-inferior nerve root distance (PIRD): distance from the inferior border of the pedicle to the superior limit of the adjacent nerve root
5. Pedicle-superior nerve root distance (PSRD): distance from the superior border of the pedicle to inferior limit of the adjacent nerve root
6. Pedicle-dural sac distance (PDSD): distance between the superior border of the pedicle and the lateral limit of the dural sac
7. Root exit angle (REA): angle between the midline and the axis of the nerve root in the frontal plane
8. Nerve root diameter (NRD): Superior-inferior diameter of the nerve root at the mid-point of the pedicles

Analysis of all measurements (mean, SD, range) were performed and calculated for each parameter. The male and female parameters were compared by using the Mann Whitney U test, and significant differences were determined as $P<0.05$ and $P<0.01$.

Results

Based on the dissection of 20 cadaver spines, the results of the current study quantitatively described the anatomic relations of the lumbar pedicles and their relations to the adjacent neural structures (Table 1, Table 2, Table 3, Fig. 4).

PW, PH, and IPD: The results of the lumbar pedicle dimensions are shown in Table 1 and Fig 4. The mean PW and PH at the L1–L5 levels ranged from 5.9 to 23.8 mm and 10.4 to 18.2 mm, respectively. The mean PH gradually decreased from L1 to L5, while the mean PW gradually increased. The IPD gradually increased from 22.2 to 27.5 mm. There were significant differences for PW and PH between males and females ($P<0.01$).

PIRD, PSRD, and PDSD: The respective average distances from the thoracic pedicle to the adjacent nerve roots superiorly, inferiorly and to dural sac medially at all levels ranged from 2.9 to 6.2 mm, 0.8 to 2.8 mm, and 0.9 mm to 2.1 mm. There was no significant difference between males and females for the PIRD, PSRD, and PDSD ($P>0.05$).

Table 1 Anatomic parameters of the lumbar pedicles measured from 20 cadavers, presented as mean±SD and range (PW pedicle width, PH pedicle height, IPD interpedicular distance)

	PW		PH		IPD	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
L1						
All	8.1±1.7	5.9–11.4	14.9±2.0	11.0–18.2	22.2±1.0	20.0–23.4
Male	8.6±1.5**	6.5–11.4	15.8±1.2**	14.2–18.2	22.2±1.1	20.0–23.4
Female	6.3±0.3	5.9–6.6	11.7±0.6	11.0–12.2	22.4±0.0	22.4–22.4
L2						
All	8.7±1.7	6.3–11.0	14.5±1.3	11.6–17.9	22.8±1.6	19.1–24.4
Male	9.3±1.4**	7.4–11.0	15.0±0.9**	14.3–17.9	22.8±1.8	19.1–24.4
Female	6.4±0.2	6.3–6.7	12.4±0.8	11.6–13.2	22.6±0.0	22.6–22.6
L3						
All	10.5±2.5	6.9–14.4	14.1±1.4	10.9–16.3	23.8±1.8	20.3–26.2
Male	11.3±2.2**	8.2–14.4	14.7±0.9**	12.5–16.3	23.9±1.9	20.3–26.2
Female	7.3±0.4	6.9–7.8	11.9±0.9	10.9–12.8	23.0±0.7	22.5–23.5
L4						
All	12.7±2.9	8.0–16.1	13.7±1.8	10.6–17.0	25.4±1.7	22.7–27.3
Male	13.9±1.9**	9.9–16.1	14.4±1.2**	11.4–17.0	26.0±1.1*	24.6–27.3
Female	8.1±0.1	8.0–8.2	11.1±0.5	10.6–11.6	22.7±0.0	22.7–22.7
L5						
All	17.2±3.4	10.9–23.8	13.6±2.0	10.4–18.2	27.5±2.7	23.1–31.7
Male	18.2±3.0**	12.4–23.8	14.3±1.4**	12.2–18.2	28.5±1.9*	26.4–31.7
Female	13.4±1.8	10.9–15.1	10.6±0.2	10.4–10.8	23.7±0.8	23.1–24.3

*$P<0.05$; **$P<0.01$

Table 2 Anatomic parameters of the lumbar pedicles in relation to the adjacent nerve roots and dural sac, measured from 20 cadavers, presented as mean±SD and range (*PIRD* pedicle-inferior nerve root distance, *PSRD* pedicle-superior nerve root distance, *PDSD* pedicle-dural sac distance)

	PIRD		PSRD		PDSD	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
L1						
All	1.6±0.4	1.1–2.4	4.0±0.7	2.9–5.2	1.3±0.2	0.9–1.6
Male	1.6±0.4	1.2–2.4	3.9±0.7	2.9–5.0	1.2±0.2	0.9–1.5
Female	1.6±0.5	1.1–2.1	4.5±0.5	4.0–5.2	1.4±0.2	1.2–1.6
L2						
All	1.7±0.3	1.4–2.3	4.5±0.6	3.7–5.4	1.5±0.3	1.1–2.1
Male	1.7±0.3	1.4–2.3	4.6±0.6	3.8–5.4	1.4±0.2	1.1–1.8
Female	1.9±0.5	1.4–2.3	4.1±0.3	3.7–4.4	1.7±0.4	1.3–2.1
L3						
All	1.6±0.4	0.8–2.6	4.8±0.8	3.6–6.2	1.5±0.3	1.2–2.1
Male	1.6±0.2	1.3–2.0	4.8±0.8	3.6–6.2	1.6±0.3	1.2–2.1
Female	1.7±0.9	0.8–2.6	4.7±0.7	4.2–5.7	1.4±0.1	1.4–1.5
L4						
All	1.6±0.4	1.2–2.8	4.9±0.6	4.2–5.8	1.6±0.3	1.1–2.0
Male	1.4±0.2	1.2–1.8	4.9±0.6	4.2–5.8	1.7±0.2	1.2–2.0
Female	2.1±0.7	1.4–2.8	5.3±0.3	4.9–5.6	1.6±0.5	1.1–2.0
L5						
All	1.5±0.1	1.3–1.9	4.8±0.7	4.0–6.1	1.4±0.2	1.2–1.8
Male	1.5±0.1	1.3–1.6	4.8±0.8	4.0–6.1	1.4±0.1	1.2–1.6
Female	1.6±0.2	1.4–1.9	4.9±0.3	4.6–5.2	1.6±0.2	1.3–1.8

$^{*}P<0.05$; $^{**}P<0.01$

REA: The REA increased consistently from 35° to 39°. The REA is more horizontal in females, especially at the L1 and L2 levels ($P<0.01$).

NRD: The NRD was between 3.3 and 3.9 mm at the L1–L5 levels. There was no significant difference between the males and females ($P>0.05$).

Table 3 Anatomic parameters of the lumbar pedicles in relation to the adjacent nerve roots, measured from 20 cadavers, presented as mean±SD and range (*REA* root exit angle, *NRD* nerve root diameter)

	REA		NRD	
	Mean±SD	Range	Mean±SD	Range
L1				
All	35.2±1.7	33–39	3.3±0.4	2.8–3.9
Male	34.5±1.1**	33–37	3.3±0.4	2.8–3.9
Female	37.3±1.5	36–39	3.1±0.1	3.0–3.1
L2				
All	36.4±1.9	34–41	3.5±0.4	3.1–4.1
Male	35.5±1.3**	34–39	3.5±0.4	3.1–4.1
Female	39.0±1.4	38–41	3.4±0.2	3.2–3.6
L3				
All	37.8±2.4	35–43	3.9±0.4	3.3–4.6
Male	36.9±1.6*	35–40	3.9±0.5	3.3–4.6
Female	40.8±2.1	39–43	3.9±0.2	3.6–4.1
L4				
All	39.3±2.3	36–44	3.9±0.5	3.1–5.2
Male	38.5±1.8*	36–41	3.9±0.6	3.1–5.2
Female	42.0±1.8	40–44	3.9±0.5	3.2–4.2
L5				
All	39.3±2.6	35–45	3.9±0.4	3.4–4.7
Male	38.5±2.2*	35–42	3.9±0.4	3.4–4.7
Female	41.8±2.4	40–45	4.2±0.4	3.8–4.5

$^{*}P<0.05$; $^{**}P<0.01$

Discussion

Pedicle screw fixation gained popularity, and became widely used in the lumbar region in Europe during the 1970s, through the work of Roy-Camille et al. [10]. The first anatomic work was done by Saillant on this subject [11]. Relevant studies present the potential risk of damaging the nerve roots, dural sac, vascular structures, and pleura as a major limitation of pedicle screw instrumentation in lumbar spine. Such injuries occur mainly because of the adjacent neural structures rather than the size of pedicle [5, 6, 8, 10, 11,12]. There are many clinical applications of lumbar transpedicular fixation. Many studies documenting this procedure, however, pay only minimal attention to complications and their incidence, and they report results based on relatively short follow-up periods. Esses et al. reported an overall total of 169 complications associated with transpedicular screw placement, based on 617 cases [5]. Of these 169 complications, nerve root violation, including transient and permanent injuries, occurred in 29 cases and cerebrospinal fluid leak in

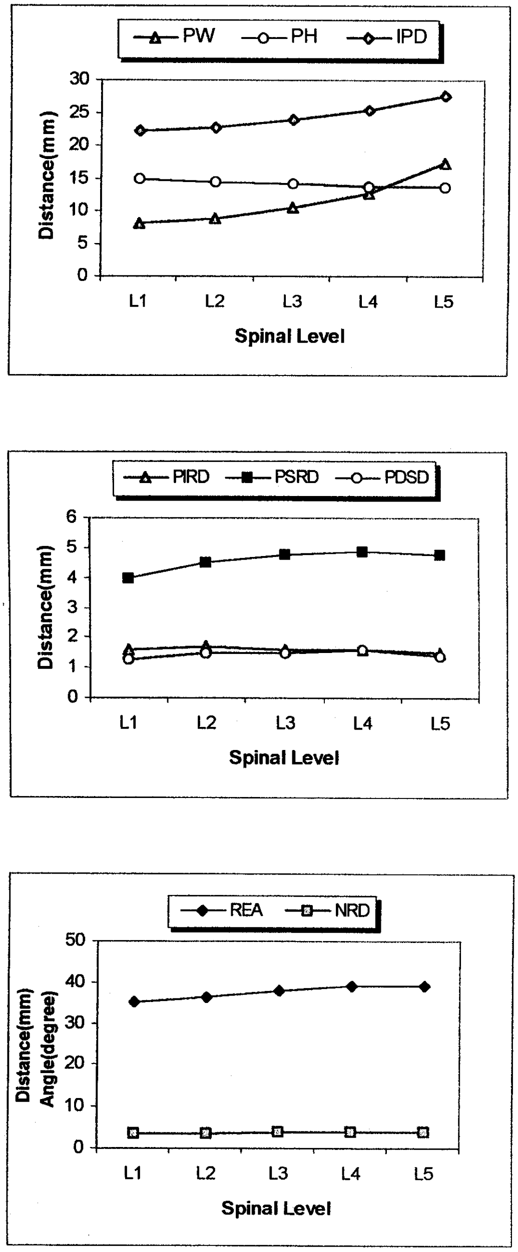

Fig. 4 Vertebral levels and measurements of lumbar pedicle and adjacent neural structures measured from 20 cadavers

12 cases. After evaluation of 57 cases of pedicular screw fixation, Matsuzaki et al. found that six patients (11%) had nerve root compression after surgery; two of them were due to direct impingement of the nerve root [9]. Luque reported 50 patients with two complications [7]. There was one infection and one transient paresthesia. Recently, Suk et al. reported the results of pedicular screw fixation in treatment of thoracic idiopathic scoliosis [12]. In their series, 13 pedicular screws (3%) were found to be displaced: six out to the superior, six out to the lateral, and one out to the inferior of the pedicle. Fortunately, no neurological deficit was reported. Because of the severity of complications related to transpedicular screwing, accurate anatomic knowledge and orientation are needed to minimize the neurological complications.

The mean PW and PH at the L1–L5 levels ranged from 5.9 to 23.8 mm and 10.4 to 18.2 mm, respectively. The mean PH and PW are much wider than in the thoracic and cervical spine, and usually do not limit the maximum diameter of a pedicular screw. The mean values were greater than 10 mm in most measurements in the current study. In this study, PIRD was lowest at L5, and PSRD and PDSD were lowest at L1. There was a higher risk of injuring the neural structures and dura at these levels. These results resemble the results of the study by Ebraheim et al. [3], who found that PW increased from L1 through L5, while PH presented no significant difference between L1 and L5. Therefore, during pedicle screw insertion, the medial and lateral risks posed by the screw decreased from L1 to L5. These results are compatible with the results of the relevant literature [2, 4, 6,13]. However, anatomic variations must be considered for safe screw placement. The average distance from the lumbar pedicle to the adjacent nerve roots, superiorly, inferiorly and to dural sac medially at all levels, ranged from 2.9 to 6.2 mm, 0.8 to 2.8 mm, and 0.9 to 2.1 mm, respectively. These results indicate that an improperly medial and caudal placement of a pedicular screw will carry a great risk of injury to the dural sac and inferior nerve root.

Our results showed that lumbar pedicles have a unique structure, and their relations with neural structures have important implications for surgical interventions. Although successful and encouraging results have been presented in some studies, the complications which may emerge during surgery can be very serious. Reported studies are few in this area, and the true incidence of complications is not certain; it may be much higher than current estimates, owing to possible under-reporting. Taking all these factors into account, more anatomic studies on the lumbar pedicles are needed to provide a three-dimensional orientation, in order to ensure a successful surgery and minimize the complications.

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