H. L. A. Defino
J. R. B. Vendrame

Role of cortical and cancellous bone of the vertebral pedicle in implant fixation

Received: 21 March 2000
Revised: 29 September 2000
Accepted: 10 October 2000
Published online: 6 February 2001
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H. L. A. Defino (✉) · J. R. B. Vendrame
Spine Surgery Service,
Department of Orthopaedics and
Trauma Surgery,
Faculty of Medicine of Ribeirão Preto,
University of São Paulo,
14049–900 Ribeirão Preto, Brazil
e-mail: hldefin@fmrp.usp.br,
Tel.: +55-16-6330336

Abstract An experimental study was conducted to determine the role of cancellous and cortical bone of vertebral pedicles in the fixation of pedicular screws. Ten segments of the lumbar spinal column removed from adults at autopsy were used. Direct measurements were made to obtain the total diameter of the pedicles from L1 to L5 plus the diameter of cancellous bone and the diameter of cortical bone. For the study, the vertebra fragments were divided into two groups, each consisting of five sets of lumbar spine segments. In the first group, the pedicle was perforated using the orientation points employed in surgical procedures (articular facet and transverse process). In the second group, a transverse cut was made in the middle portion of the pedicle so that perforation and introduction of the screws could be performed under direct view. After pedicle perforation using a 3-mm drill, the screws were introduced into

the vertebral pedicle in increasing order of diameter size, until structural alteration of the pedicle was observed (plastic deformation or rupture). These parameters were evaluated by means of successive measurements with a pachymeter and by direct observation. The screws used ranged in diameter from 3 to 12.5 mm, with progressive 0.5-mm increments. The analysis of the alterations in pedicle structure was performed by considering total diameter, spongy bone diameter, cortical bone diameter, and diameter of the screw used to produce the structural alteration. The results showed that the screws in general presented fixation mainly in the cancellous bone portion of the vertebral pedicle, whereas a small percentage of cortical bone was used for fixation.

Keywords Transpedicular instrumentation · Pedicle screws · Lumbar spine

Introduction

The use of the vertebral pedicle as a site for implant fixation has been a routine procedure in European countries since 1961 [10]. In view of the biomechanical advantages of pedicular fixation systems, which provide more three-dimensional stability to the vertebral segment with a smaller area of instrumentation, this modality of vertebral fixation has been gaining increasingly widespread acceptance [2, 3, 5].

As a result of its clinical utilization, the vertebral pedicle has been intensely studied, and the importance of the role of pedicular cortical bone in the fixation of screws introduced into the pedicle has been questioned [7]. This questioning, which goes against classical concepts [10], attracted our interest because of its clinical importance. The main objective of the present study was to study experimentally the role of cortical bone and cancellous bone of the vertebral pedicle in the fixation of implants introduced into this structure.

Material and methods

We studied ten segments of the lumbar spinal column (L1–L5) removed at autopsy from adults ranging in age from 27 to 88 years (mean 74 years). The removed vertebrae did not present fractures or metastatic disease, as determined by macroscopic examination and by verification of the medical records of the patients.

The soft tissues inserted into the vertebrae were removed and the vertebral disks were sectioned so that the vertebrae of interest were separated from the whole set. One spine presented L5 sacralization, and only four vertebrae were therefore available for study; the remaining ones had five lumbar vertebrae.

The procedure mainly consisted of the insertion of screws of increasing diameter into the vertebral pedicles while monitoring the outer diameter of the latter with the aid of a sensitive pachymeter and observing changes in the morphology of the external wall of the pedicle after insertion of each successive screw (Fig. 1, Fig. 2).

We used a set of 20 stainless steel screws, specially manufactured for the study, ranging in diameter from 3 to 12.5 mm, with 0.5-mm increments, and of sufficient length to cross the entire extension of the vertebral pedicle.

The spines were divided into two experimental groups (groups I and II), consisting of five lumbar spines each (L1–L5). In group I, the screws were introduced bilaterally into the vertebral pedicle from L1 to L5, according to the anatomical reference points routinely used in surgery. The site of implant introduction corresponded to the intersection of the lines that passed through half of the transverse process and through the lateral side of the upper articular surface. In group II, the vertebral pedicles were sectioned transversely at their thinnest point, and the screws were introduced into their most central point under direct vision. In this group, the screws were also introduced into both vertebral pedicles in increasing order of diameter.

The introduction of the screws in groups I and II was started by perforating the pedicle with a 3-mm drill. The direction of the screw on the horizontal plane followed the axis of the pedicle, which it was possible to observe directly, and the screws were introduced starting at a diameter of 3 mm, with 0.5-mm progressions, until alteration in the outer diameter of the pedicle was observed. The value of the widest diameter of the screw introduced into the pedicle without causing changes in the outer wall of the pedicle was then recorded and compared with the values of the diameters of cortical bone and cancellous bone and with the outer diameter of the pedicle. The narrowest dimension in the transverse plane was considered the diameter of the pedicle.

The diameter of pedicular cortical bone and cancellous bone was determined by direct measurement with a pachymeter before introduction of the screws in group II, and after introduction of the screws in group I, with the pedicles being cut transversely at their narrowest point.

We studied the types of alteration of the outer wall of the vertebral pedicle provoked by the introduction of the screw, and the correlation of the diameter of the largest screw that could be inserted into the vertebral pedicle without alterations in the outer wall of the pedicle with the diameter of cancellous bone and with the outer diameter of the pedicle (both absolute and percentage values), the percentage of the pedicle diameter occupied by the largest screw, and the variation by spinal level in the diameters of the largest screws that could be inserted into the pedicle without causing alterations of this structure.

The values for groups I and II were analyzed statistically by the exact Fisher test and by ANOVA.

Fig. 1 Photograph of sections of the vertebral pedicles on the coronal (A) and sagittal (B) plane, showing their contingent of cancellous and cortical bone (asterisk). Observe the scarce amount of cortical bone in both sections

Fig. 2 Photographs illustrating the mode of implant insertion in group I (A,B) and group II (C,D)

Results

The morphological alterations of the outer wall of the vertebral pedicle caused by the introduction of screws of increasing diameter into the structure were classified as plastic deformation (expansion of the outer walls of the pedicle that was macroscopically visible and altered the reading of the pachymeter but did not present solution of continuity on the wall), and rupture (a lesion consisting of a fissure of the pedicular wall, with alteration of the reading of the pachymeter).

The diameters of the pedicle and cancellous bone for groups I and II are presented in Table 1 and Table 2, together with values for the widest screw diameter that did not produce an alteration in the pedicular wall and a description of the type of alteration observed with the introduction of the screw of widest diameter. The values observed in four vertebrae in groups I and II were discarded because of erroneous measurements. Thus, the data for group I concern 46 pedicles and the data for group II 44 pedicles.

With regard to the largest screw diameter ("largest screws") that could be inserted without alteration in the

pedicular wall, 24 largest screws (63.1%) had a smaller diameter than the diameter of pedicular cancellous bone in group I, as opposed to 18 of the largest screws (48.6%) in group II. No significant difference was observed between groups, although fewer largest screws with a diameter less than that of cancellous bone were observed in group II – a fact possibly explained by the more centrally positioned introduction of the screws.

In group I, the diameter of cancellous bone of 17 pedicles was less than 6.5 mm (range 2.3–6.4 mm), and among the screws that did not cause changes in the pedicular wall, 16 had a diameter of less than 6.5 mm. In group II, the diameter of cancellous bone of 18 pedicles was less than 6.5 mm (range 3.8–6.4 mm) and ten largest screws had a diameter of less than 6.5 mm.

Plastic deformation was the type of alteration most frequently observed in both groups. In group I, plastic deformation was observed in 33 pedicles (71.7%) and rupture in 13 (28.3%), and in group II plastic deformation was observed in 26 pedicles (59.1%) and rupture in 18 (40.9%) (Table 1, Table 2). The exact Fisher test showed no significant difference between the two groups ($P=0.268$).

Table 1 Group I: diameters (mm) of the pedicle (*P*) of cancellous bone (*C*), and of the widest screw that did not cause alterations of the outer wall when inserted into the pedicle (*S*), and types of alterations observed after the insertion of screws of a wider diameter (missing values are due to errors in the measuring)

Level	Spine 1		Spine 2		Spine 3		Spine 4		Spine 5	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
L1	P	–	–	6.7	5.4	9.7	10.1	5.1	–	–
	C	–	–	3.7	4	6.6	8	2.9	–	–
	S	–	–	5	3.5	6.5	6	4	–	–
	Structural alteration	–	–	Plastic deformation	Rupture	Plastic deformation	Plastic deformation	Plastic deformation	–	–
L2	P	11.7	9.7	6.6	7	9.9	8.3	9.7	6.7	6.4
	C	9.1	7.4	4.9	4.4	7	5.2	7	4.8	4.6
	S	9.5	8.5	4.5	6.5	5	5	6.5	4.5	5
	Structural alteration	Rupture	Rupture	Plastic deformation	Rupture	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation
L3	P	11.4	11.3	11.6	10.3	9.4	10.9	12	8.3	9.1
	C	8.2	7.8	8.5	7.9	4.5	6.5	8.3	6.4	4.6
	S	10	9	9	9	5	6	6.5	5	5
	Structural alteration	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Rupture	Plastic deformation	Plastic deformation
L4	P	11.8	13.3	11.8	13.9	9.2	8.9	12.8	9.4	9.4
	C	9.2	9.7	9.1	11.7	4.4	5.1	8.3	3.3	6.6
	S	10.5	10.5	9.5	9.5	6	6	6.5	7	6
	Structural alteration	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Rupture	Plastic deformation	Plastic deformation
L5	P	12.4	12.5	13.2	13.6	12.8	11.7	12.8	12.9	11.1
	C	9.2	9.8	9.2	10.5	8.7	7.3	9.3	10.4	7.7
	S	9	9	9.5	10	6.5	7	12	9	6.5
	Structural alteration	Rupture	Rupture	Plastic deformation	Plastic deformation	Plastic deformation	Rupture	Rupture	Rupture	Plastic deformation

Table 2 Group II: diameters (mm) of the pedicle (*P*) and of cancellous bone (*C*) and of the widest screw that did not cause alterations of the outer wall when inserted into the pedicle (*S*), and types of alterations observed after the insertion of screws of wider diameter (missing values are due to errors in the measuring)

Level	Spine 6			Spine 7			Spine 8			Spine 9			Spine 10		
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
L1	P	7.8	7.3	9.8	9.3	7.3	8.4	6.3	6	—	—	—	—	—	—
	C	5.5	5	7.2	6.4	5.3	5.7	4	4	—	—	—	—	—	—
	S	6	5	8	6.5	5.5	7	5	4.5	—	—	—	—	—	—
	Structural alteration	Rupture	Rupture	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	—	—	—	—	—	—
L2	P	8.1	7.6	12	12	7.5	8	9.3	9.4	—	—	—	—	—	—
	C	5.6	5	9.6	9.3	5.8	4.9	7.3	7.2	—	—	—	—	—	—
	S	6.5	5	8.5	10.5	6.5	6.5	7.5	7	—	—	—	—	—	—
	Structural alteration	Rupture	Plastic deformation	Plastic deformation	Rupture	Plastic deformation	Plastic deformation	Rupture	Rupture	—	—	—	—	—	—
L3	P	10.1	10.1	11.4	11.5	11.5	11.8	11.1	11.1	6.6	7.5	6.6	7.5	6.6	7.5
	C	7.2	7.3	8.5	9.1	7.9	8.6	9	8.1	4.4	4.9	4.4	4.9	4.4	4.9
	S	8.5	8.5	8.5	10.5	9.5	8.5	7.8	8	5	6	5	6	5	6
	Structural alteration	Plastic deformation	Rupture	Rupture	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Rupture	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation
L4	P	9.6	10.1	11.9	11.9	10.4	9.7	13.5	12.3	8.8	7.8	8.8	7.8	8.8	7.8
	C	6.5	7	9.8	9.5	7.6	6.4	9.9	8.7	5.8	3.8	5.8	3.8	5.8	3.8
	S	6.5	6.5	10.5	10.5	6.5	6.5	8	9.5	7	5	7	5	7	5
	Structural alteration	Plastic deformation	Rupture	Rupture	Rupture	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Plastic deformation	Rupture	Plastic deformation	Rupture	Plastic deformation	Rupture
L5	P	11.1	10	10.5	12.2	11.98	14.4	n/a ^a	n/a ^a	9.7	9.4	9.7	9.4	9.7	9.4
	C	6	5.8	8.1	10	8.7	10.8	n/a ^a	n/a ^a	7	7	7	7	7	7
	S	5	6.5	8.5	9.5	8	9.5	n/a ^a	n/a ^a	8.5	8.5	8.5	8.5	8.5	8.5
	Structural alteration	Plastic deformation	Plastic deformation	Rupture	Rupture	Plastic deformation	Rupture	n/a ^a	n/a ^a	Rupture	Rupture	Rupture	Rupture	Rupture	Rupture

^aVertebral column with four lumbar vertebrae

Table 3 Group I: values of the diameters of cortical bone and spongy bone of the vertebral pedicle, and of the largest screw inserted that did not cause alteration of the outer wall of the pedicle, expressed as a percentage of the diameter of the vertebral pedicle (missing values are due to errors in the measuring)

Level		Spine 1		Spine 2		Spine 3		Spine 4		Spine 5	
		Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
L1	Cortical	–	–	25.7	44.73	20.4	31.51	43.64	43.11	–	–
	Cancellous	–	–	74.3	55.27	79.6	68.49	56.36	56.89	–	–
	Screw	–	–	65.18	74.29	59.7	67.15	99.75	78.74	–	–
L2	Cortical	24.13	21.92	37.11	26.17	36.79	29.16	36.72	31.17	27.94	27.87
	Cancellous	75.87	78.08	62.89	73.83	63.21	70.84	63.28	68.83	72.06	72.11
	Screw	87.27	81.34	93.26	68.08	60.31	50.45	80.99	66.87	78.49	67.47
L3	Cortical	31.03	27.97	23.03	26.9	40.33	52.03	44.7	31.17	38.88	22.96
	Cancellous	68.97	72.03	76.97	73.1	59.67	47.97	55.3	68.83	61.12	77.04
	Screw	79.58	87.41	87.46	77.59	55	53.42	53.43	54.17	55.07	60.1
L4	Cortical	49.7	22.12	16.01	22.54	42.73	52.4	33.01	35.08	29.14	64.6
	Cancellous	50.3	77.88	83.99	77.46	52.27	47.6	66.99	64.92	70.86	35.4
	Screw	78.94	88.98	68.2	80.51	67.64	65.5	56.92	50.78	64.03	74.87
L5	Cortical	21.97	25.55	22.95	30.05	37.17	32.19	23.2	27.96	30.32	19.36
	Cancellous	78.03	74.45	77.05	69.95	62.83	67.81	76.8	72.04	69.68	80.64
	Screw	71.88	72.76	73.31	72.08	60.09	50.66	79.37	93.46	58.82	69.98

Table 4 Group II: values of the diameter of cortical bone and spongy bone of the vertebral pedicle, and of the diameter of the largest screw inserted that did not cause alteration of the outer wall of the pedicle, expressed as a percentage of the diameter of the vertebral pedicle (missing values are due to errors in the measuring)

Level		Spine 6		Spine 7		Spine 8		Spine 9		Spine 10	
		Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
L1	Cortical	32.15	29.18	31.73	26.28	31.67	27.51	33.17	36.13	–	–
	Cancellous	67.85	70.82	68.27	73.72	68.33	72.49	66.83	63.87	–	–
	Screw	68.4	77.12	69.67	81.8	83.33	75.65	75	79.24	–	–
L2	Cortical	34.25	31.4	22.49	20.7	38.87	21.95	23.4	21.76	–	–
	Cancellous	65.75	68.6	77.51	79.3	61.13	78.05	76.6	78.24	–	–
	Screw	65.62	80.35	87.79	70.36	81.25	87.01	74.47	80.39	–	–
L3	Cortical	27.36	29.14	20.97	25.13	27.18	30.72	27.01	18.37	35.15	33.48
	Cancellous	72.64	70.86	79.03	74.87	72.82	69.28	72.99	81.63	64.85	66.52
	Screw	84.58	84.24	90.99	74.69	71.97	82.9	72.27	70.59	79.89	75.76
L4	Cortical	30.65	32.88	20.05	17.13	33.58	27.5	28.99	26.46	51.67	34.5
	Cancellous	69.35	67.12	79.95	82.87	66.42	72.5	71.01	73.54	48.33	65.5
	Screw	64.68	67.43	88.09	88.61	67.36	62.5	77.36	59.3	64.1	79.19
L5	Cortical	41.72	45.67	18.03	22.86	65.97	26.99	n/a ^a	n/a ^a	24.81	27.23
	Cancellous	58.28	54.33	81.97	77.14	75.14	73.01	n/a ^a	n/a ^a	75.19	72.75
	Screw	71.64.87	45.13	77.87	80.85	65.97	67.06	n/a ^a	n/a ^a	90.91	79.19

^a Vertebral column with four lumbar vertebrae

Table 3 and Table 4 show the percentages of cortical and cancellous bone of the pedicle and the percentage of the pedicular diameter occupied by the screw. The mean percentage of occupation of the pedicular diameter by the screw of largest caliber that did not produce alteration of the pedicular wall was 70.7% in group I and 75.38% in group II. The difference between groups was not statistically significant and can be explained by the introduction of the screws in a more central location in group II. The mean percentages of the diameter of cancellous bone and cortical bone and the percentage of the pedicular diameter occupied by the screw in groups I and II are illustrated in Fig. 3 and Fig. 4.

Analysis of the diameters of the largest screws that did not produce alterations in the outer wall of the pedicle showed wide variability at the different spinal levels in both groups studied, demonstrating the great variation in the diameters of the vertebral pedicles, which has been well documented in previous morphological studies. Table 5, Fig. 5 and Fig. 6 show the greatest and smallest values of the diameters of the screws that did not produce alterations in the pedicular wall at the different spinal levels in the two groups studied.

Fig.3 Graph illustrating the mean values of the diameter of spongy bone and the diameter of the largest screw that did not cause any alteration in the outer wall of the pedicle, expressed as percentages of the mean outer diameter of the pedicle (100%) in the vertebrae of group I

Fig.4 Graph illustrating the mean values of the diameter of spongy bone and the diameter of the largest screw that did not cause any alteration in the outer wall of the pedicle, expressed as percentages of the mean outer diameter of the pedicle (100%) in the vertebrae of group II

Table 5 Maximum, minimum and mean values of the diameter of the largest screws that did not cause alteration of the outer wall of the pedicle in groups I and II

Level	Group	Maximum (mm)	Mean (mm)	Minimum (mm)
L1	I	6.5	4.8	3.5
	II	8	5.9	4.5
L2	I	9.5	6.3	4.5
	II	10.5	7.3	5
L3	I	10	7.1	5
	II	10.5	8.1	5
L4	I	10.5	7.8	6
	II	10.5	7.7	5
L5	I	12	8.9	6.5
	II	9.5	8	5

Discussion

The vertebral pedicle is classically considered to be a cylindrical structure of cortical bone filled with a small amount of cancellous bone in whose medial and inferior borders are located the roots of the spinal nerves [11]. However, this classical description of this vertebral portion does not correspond to reality, since transverse sections show that the pedicles are tear shaped or kidney shaped and contain a small amount of cortical bone and abundant cancellous bone [4, 9]. Morphometric studies have demonstrated these characteristics of the vertebral pedicles, as well as the fact that their three-dimensional structure is quite complex and varies across different segments of the spine, and that the pedicle should not be considered simply to be a cylindrical bone structure [9].

Fig.5 Graph illustrating the maximum, minimum and mean values of the diameters of the largest screws that did not cause any alterations in the outer wall of the vertebral pedicle at the different levels of the lumbar spine in group I

Fig.6 Graph illustrating the maximum, minimum and mean values of the diameters of the largest screws that did not cause any alterations in the outer wall of the vertebral pedicle at the different levels of the lumbar spine in group II

Alterations in the outer diameter of the pedicle after the introduction of implants of a wider diameter than the diameter of cancellous bone were observed by Misenhimer et al. [7] in an experimental study, and the results of our study agree with the findings reported by these authors, who also observed a variety of patterns of alter-

ations in the outer diameter of the vertebral pedicles, consisting of plastic deformation or rupture. These investigators also reported the occurrence of fracture of the pedicle in specimens already presenting plastic pedicular deformation following the insertion of a screw of wider diameter.

We believe that plastic deformation occurs in all pedicles before their rupture. In the cases in which we observed rupture of the pedicle after introduction of the screw, we believe the method used to detect the alteration was imprecise and the diameter of the screw exceeded the capacity for tolerance of the pedicle, despite the progressive increase in diameter in 0.5-mm increments.

The use of two experimental models in the present study, one of them simulating the clinical application of pedicular fixations and the other consisting of the introduction of implants into the center of the pedicle under direct vision, in order to eliminate the possible effects of eccentric implant placement, showed a slight qualitative difference in the type of alteration observed in the pedicles, with the distribution of the type of alteration being more homogeneous in group II. This was probably due to the more central location of the introduction of the implants, although it should be pointed out that the transverse cut of the pedicle may have weakened it. The pedicular alterations observed in the two groups were similar, and we cannot attribute the occurrence of the alterations observed to the eccentric positioning of the implant in group I, which simulated the clinical situation, since the same alterations were also observed in group II. Thus, we may conclude that the more central placement of implants would not eliminate the problem observed.

The present results demonstrate that the cortical bone of the vertebral pedicle does not participate to an important extent in the fixation of implants placed inside the

vertebral pedicles. Even when screws of a wider diameter than routinely used in surgery were inserted, we observed that a high proportion of the implanted screws were of smaller diameter than that of the cancellous bone inside the pedicles. Analysis of the values of the mean diameters of the largest screws, of cortical bone and of spongy bone of the pedicles, considering absolute values or even percentages, clearly demonstrated the lack of participation of cortical bone of the vertebral pedicle in implant fixation, even when implants of wider diameter were used.

This fact should be considered when planning surgical procedures. Another important observation was that some vertebrae of some spines in both groups had a cancellous bone diameter of less than 6.5 mm (17 in group I and 18 in group II) and that alterations in pedicle diameter were observed with the use of implants of relatively small diameter, actually smaller than those of implants available on the market (16 largest screws were less than 6.5 mm in diameter in group I and 10 in group II). These observations support the importance of individual preoperative evaluation, and confirm data obtained in other studies that demonstrated wide variations in the dimensions of this vertebral structure [1, 6, 8].

The present results indicate that pedicular screws do not achieve fixation by anchorage in the cortical bone of vertebral pedicles, but rather by anchorage in the cancellous bone inside the pedicles – an observation that should be considered in the utilization and planning of implants for pedicular fixation.

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