PULLOUT STRENGTH OF PEDICLE SCREWS VERSUS PEDICLE AND LAMINAR HOOKS IN THE THORACIC SPINE

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While the biomechanical properties of pedicle screws have proven to be superior in the lumbar spine, little is known concerning pullout strength of pedicle screws in comparison to hooks in the thoracic spine. In vitro biomechanical pullout testing was performed to evaluate the axial pullout strength of pedicle screws versus pedicle and laminar hooks in the thoracic spine with regard to surgical correction techniques in scoliosis.

Nine human cadaveric thoracic spines were harvested and disarticulated. To simulate a typical posterior segmental scoliosis instrumentation, standard pedicle hooks were used between T4 and T8 and supralaminar hooks between T9 and T12 and tested against pedicle screws. The pedicle screws were loaded strictly longitudinal to their axis ; the hooks were loaded perpendicular to the intended rod direction. In total, 90 pullout tests were performed.

Average pullout strength of the pedicle screws was significantly higher than in the hook group (T4-T8 : 531 N versus 321 N, T9-T12 : 807 N versus 600 N, $p < 0.05$). Both screw diameter and the bone mineral density (BMD) had significant influence on the pullout strength in the screw group.

For scoliosis correction, pedicle screws might be beneficial, especially for rigid thoracic curves, since they are significantly more resistant to axial pullout than both pedicle and laminar hooks.

Keywords : pedicle screw ; pedicle hook ; laminar hook ; pullout strength ; thoracic spine ; scoliosis.

Mots-clés : vis péduculaire ; crochet péduculaire ; crochet lamaire ; résistance en traction ; rachis dorsal ; scoliose.

INTRODUCTION

Pedicle screws have become widely accepted as an invaluable part of spinal instrumentation (5). Even in scoliosis surgery, pedicle screw instrumentation has gained in popularity owing to better three-dimensional correction as well as shorter fusion length and less loss of correction compared to hook fixation for lumbar curves (2, 5, 13). Several studies have demonstrated the superior biomechanical properties of pedicle screws for spinal fixation of the lumbar spine (16, 17).

In thoracic scoliosis, however, the role of pedicle screw instrumentation is controversial. Some authors report better correction results with pedicle screws compared to hooks even in the thoracic spine (18, 27). However, concerns have arisen with respect to the confined anatomical dimensions. Problems may include the concave pedicles being too small to accept pedicle screws (19) and the potential complications of their use (22, 24).

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Furthermore, the biomechanical advantages of pedicle screw fixation in the small pedicles especially of the upper and middle thoracic spine are questionable. In the current literature there is a paucity of data on the biomechanical properties of pedicle screws in comparison to pedicle or laminar hooks in the thoracic spine. The aim of this study was to measure the pullout strength of pedicle screws versus pedicle and laminar hooks in the human thoracic spine as they are used in surgical correction techniques in scoliosis.

METHODS

Nine fresh frozen human cadaveric thoracic spines (T4-T12) were harvested en bloc and stored at -20°C. The average age of the seven female and two male donors was 74.3 years (60-89 years). An AP and lateral x-ray were obtained from each specimen to exclude osteolysis due to malignancy or fracture.

To determine the bone mineral density (BMD) of the specimens quantitative computed tomography (QCT) was performed in a single energy technique (Tomoscan LX, Philips, Best, The Netherlands). In five representative vertebrae of each of the nine specimens, midvertebral sections with a collimation of 10 mm were obtained with an exposure dose of 200 mAs and 120 kVp. Trabecular BMD was measured in an oval region of interest (ROI) using a Cann-Genant phantom (Image Analysis, Columbia, KY, USA) for calibration. An average bone density of 109.7 mg hydroxyapatite/ml (67.3-162.6 mg/ml) was calculated. According to the WHO definition of osteoporosis and the normal reference population at our institution a BMD of less than 80 mg hydroxyapatite/ml was considered as osteoporotic (20, 29). Thus, two specimens were classified as osteoporotic.

Each specimen was cleared of remaining soft tissue and carefully disarticulated. Pedicle width and height were recorded at their narrowest points (isthmus) with a precision caliper. Standard titanium pedicle hooks and thoracic laminar hooks as well as pedicle screws of different diameter (4.8 mm, 5.5 mm, 6.5 mm, 7.2 mm) and length (35 mm, 40 mm, 45 mm, 50 mm) were used for testing (Münster Posterior Double Rod System, Schäfer Micomed, Schorndorf, Germany) (fig. 1). As in a typical posterior segmental instrumentation, standard pedicle hooks were used between T4 and T8 and supralaminar hooks between T9 and T12 and tested against pedicle screws (3, 8).

Fig. 1. — The tested implants : Standard titanium thoracic laminar hook, pedicle hook and pedicle screw (as an example a 40 mm long, 5.5 mm diameter screw).

The pedicle screws were inserted under direct visual control after entering and widening the pedicle with an awl. The largest possible screw length and diameter without cortical penetration was chosen. Between T4 and T8 4.8 mm or 5.5 mm diameter screws with 35 or 40 mm in length were used. However, in six vertebrae slight lateral pedicle screw penetration occurred because of the small pedicle width. At the lower thoracic spine screw length varied between 45 and 50 mm and screw diameter between 5.5 and 7.2 mm. The supralaminar hook was placed in a typical fashion with caudal direction after fixation of the vertebrae. The pedicle hook was placed after partial resection of the inferior articular process ensuring a good bilateral pedicle grip.

Each vertebra was mounted in a jig that was fixed on a specially designed platform allowing three-dimensional alignment (figs. 2, 3). Pullout testing was performed with loading of the pedicle screw strictly longitudinal to its axis. The hooks were all loaded perpendicular to the intended rod direction (fig. 2b). The screw heads and hooks were firmly fixed to the load cell of the material testing machine (Type 1TZZ, Otto Wolpert, Ludwigshafen, Germany). The testing mode was controlled by displacement at a constant rate of 5 mm/min until pullout of the implant or vertebral fracture. Pullout strength was recorded in newtons (N) as the maximal resistance of the implant to the tensile force applied along the axis of the screws respectively perpendicular to the intended

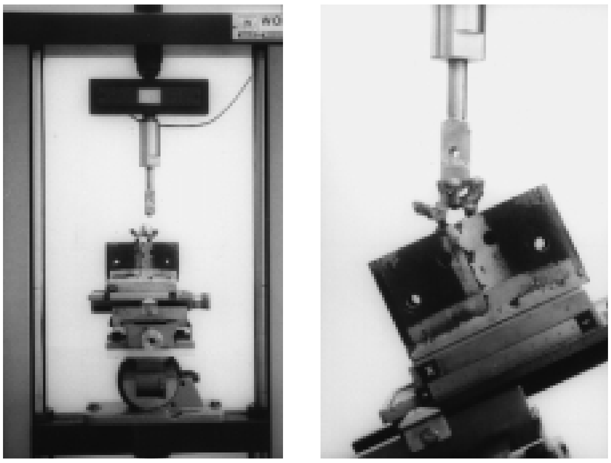

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Fig. 2. — Complete test set-up with material testing machine and a thoracic vertebra (D11) mounted in the jig with a supralaminar hook to be tested. The specially designed platform allows three-dimensional alignment to achieve a strictly axial pullout test perpendicular to the intended rod direction. Before (a) and after (b) alignment.

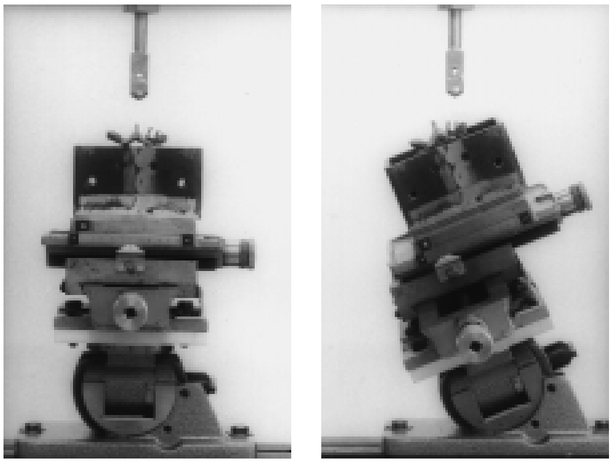

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Fig. 3. — Example of test set-up of an eighth thoracic vertebra and a pedicle screw to be tested. Before (a) and after (b) alignment.

rod direction for the hooks. The failure mode as well as the load-displacement curve including failure displacement were registered.

In an alternating fashion each hook was tested against a screw on the contralateral side of the adjacent vertebra. However, in case of a clean pedicle screw or laminar hook pullout the contralateral side of the same vertebra was used for testing, since these failure modes did not impair the fixation strength of the contralateral side. In total, 54 vertebrae were tested unilaterally and 18 vertebrae bilaterally. Nine vertebrae were not available for testing owing to damage during harvesting or disarticulation. In the upper thoracic spine (T4-T8) 27 screws and hooks were tested ; in the lower thoracic spine (T9-T12) 18 screws and hooks.

Statistical analysis was carried out with the Wilcoxon signed rank test and the Mann-Whitney-U-Test. The Pearson correlation coefficient (r) was used for correlation analysis. A value of $p < 0.05$ was considered significant.

RESULTS

The average pedicle width and height of the individual vertebral levels are summarized in table I. The average pullout strength was significantly greater for the pedicle screws both in the upper and

Table I. — Average values for pedicle width and pedicle height (range in parentheses)

	pedicle width (mm)	pedicle height (mm)
T4	5.1 ± 1.1 (3.3-7.1)	11.9 ± 1.2 (9.7-14.0)
T5	5.0 ± 1.5 (3.6-7.2)	11.5 ± 1.2 (10.0-14.3)
T6	5.1 ± 1.2 (3.7-7.2)	11.4 ± 1.3 (9.7-13.9)
T7	5.4 ± 1.4 (3.8-7.5)	11.6 ± 1.4 (9.2-14.6)
T8	6.0 ± 1.3 (4.3-9.3)	12.0 ± 1.3 (10.0-14.6)
T9	6.6 ± 1.4 (4.8-9.3)	12.5 ± 1.6 (10.2-15.8)
T10	7.4 ± 1.3 (4.8-10.8)	14.5 ± 1.8 (12.1-18.9)
T11	8.8 ± 1.0 (7.5-11.0)	16.4 ± 1.0 (14.2-18.3)
T12	8.7 ± 1.3 (6.9-10.7)	17.2 ± 0.8 (15.6-18.8)

lower thoracic spine in comparison to the pedicle hooks and laminar hooks (table II). Both screws ($p = 0.0058$) and hooks ($p < 0.0001$) showed a significantly greater pullout strength in the lower thoracic spine compared to the upper thoracic spine. The 7.2 mm diameter screw had a significantly greater pullout strength than the 4.8 mm screw ($p = 0.0012$). The different loads to failure averaged 527.4 ± 187.8 N (4.8 mm screw, n = 16), 744.8 ± 226.7 N (5.5 mm screw, n = 11), 698.5 ± 253.2 N (6.5 mm screw, n = 8) and 923.1 ± 173.2 N (7.2 mm screw, n = 10).

Table II. — Average pullout strength of pedicle screws and pedicle and laminar hooks

	upper thoracic spine (T4-T8)			lower thoracic spine (T9-T12)		
	pedicle screw	pedicle hook	p-value	pedicle screw	laminar hook	p-value
pullout strength	531.7 ± 213.8 N (224-1072 N)	321.4 ± 111.6 N (117-579 N)	< 0.0001	807.9 ± 207 N (458-1221 N)	600.1 ± 167.2 N (299-891 N)	0.02

Table III. — Failure modes of pedicle screws and pedicle and laminar hooks

	Failure mode
Pedicle screws	23 x clean pullout 17 x ipsilateral pedicle fracture 5 x bilateral pedicle fracture
Pedicle hooks	20 x ipsilateral pedicle fracture 4 x bilateral pedicle fracture 3 x fracture of articular process
Laminar hooks	12 x lamina fracture 3 x ipsilateral pedicle fracture 3 x bilateral pedicle fracture

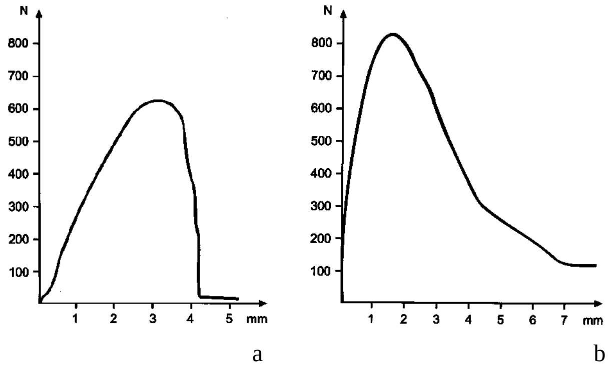

Fig. 4. — Load-displacement curves of a laminar hook at D10 (a) and a pedicle screw at D11 (b). Note the steep rise of the screw curve and the relatively short failure displacement compared to the hook.

The different failure modes are summarized in table III. The average failure displacement was 1.7 ± 0.6 mm (screw, T4-T8), 2.2 ± 0.7 mm (screw, T9-T12), 3.3 ± 1.1 mm (pedicle hook) and 3.1 ± 1.0 mm (laminar hook) (figs. 4a, b).

Correlation between BMD and pullout strength was significant for both pedicle hooks ($r = 0.87$, $p < 0.05$) and screws ($r = 0.92$, $p < 0.05$). However, there was no significant correlation between BMD and average pullout strength of the laminar hooks ($r = 0.25$, $p > 0.05$).

DISCUSSION

The aim of this study was to compare axial pullout strength of pedicle screws versus pedicle hooks and laminar hooks in the human thoracic spine with regard to surgical correction techniques in scoliosis. Since T8 represents the apical vertebra in most thoracic curves (15), pedicle hooks were used at T8 and above and supralaminar hooks below T8 and tested against pedicle screws simulating typical posterior instrumentation for scoliosis correction (3, 8). In modern posterior scoliosis surgery the predominant correction technique is translation either by rod rotation or by segmental approximation (1, 8, 21, 28). During this maneuver the fixation anchors on the concavity of the curve are maximally loaded under tensile forces along the axis of the screws perpendicular to the intended rod direction for the hooks. The apical region of a scoliotic curve resembles the area of maximal deformity and rigidity (1). Therefore, maximal resistance to tensile forces is decisive with respect to an optimal three-dimensional curve correction and to prevent pullout of the implants during curve correction.

Axial pullout testing showed a significantly greater pullout strength of pedicle screws compared to hooks in both the upper and lower thoracic spine. In the current literature there is a paucity of data concerning comparative biomechanical testing of pedicle and laminar hooks versus pedicle screws in the thoracic spine. Berlemann *et al.* (4) analyzed the pullout strength of different pedicle hooks in the thoracic spine with respect to a special hook design combined with a 3.2-mm screw. Comparative testing showed a significantly higher pullout strength of specially designed pedicle hooks with one or two screws than the standard pedicle hooks. Pedicle screws were only tested in a small series of ten tests, demonstrating a greater pullout strength compared to the standard pedicle hook.

In this study the average pullout strength was significantly higher for the pedicle screws in the lower compared to the upper thoracic spine. These results can be explained by the greater pedicle widths in the lower thoracic spine and thus greater screw diameter used (between 5.5 mm and 7.2 mm screws) compared to the upper thoracic spine (mainly 4.8 mm). Biomechanical studies have proven the close relationship between pedicle screw diameter and axial fixation strength (11, 25, 31). Furthermore, the laminar hooks in the lower thoracic spine had a significantly higher pullout strength compared to the pedicle hooks in the upper thoracic spine. While the laminar hooks most frequently failed by pullout through the lamina, the failure mode of the pedicle hooks was predominantly ipsilateral pedicle fracture. These results are confirmed by Butler *et al.* who analyzed the axial pullout strength of different sublaminar wire and laminar hook constructs and found a significant correlation between pedicle diameter and fixation strength in the thoracic spine (6).

While Freedman *et al.* (10) tested the stability of pedicle hooks and laminar hooks under distractive forces, reports on comparative axial testing of laminar and pedicle hooks are not available in the current literature to the best of our knowledge. Jacobs *et al.* (14) tested the axial pullout strength of standard Harrington laminar hooks and specially designed locking laminar hooks in human thoracolumbar cadaver spines and found an average pullout strength of 130 kp for the locking hook and 81 kp for the standard hook ($p < 0.005$). Butler *et al.* analyzed the axial pullout strength of different sublaminar wire and laminar hook constructs in osteoporotic thoracic spines. They found average loads to failure of between 296 and 358 N (6).

Osteoporosis has been identified as a major factor impairing the fixation strength of pedicle screws (9, 12, 25, 26, 30, 31). Coe *et al.* (7) tested pedicle screws and Harrington laminar hooks in seven osteoporotic human thoracolumbar cadaver spines and found a significantly higher axial pullout strength for the hooks (646 N) compared to the pedicle screws (Cotrel-Dubousset screws : 345 N ; Steffee screws : 430 N). In a similar study (23), however, these results could not be confirmed. Axial pullout testing showed a higher pullout strength in the screw group compared to the laminar hooks. As with our results, these two studies did not find any significant correlation between BMD and pullout strength of the laminar hooks, whereas there was a significant correlation between pullout strength of pedicle screws and BMD.

In conclusion, this experimental cadaver study shows that pedicle screws offer a significantly higher pullout strength compared to both laminar and pedicle hooks in the thoracic spine. Since predominantly tensile forces are applied during scoliosis correction, pedicle screws might permit a better curve correction especially in rigid curves, provided that pedicle size and screw diameter allow a safe pedicle screw placement.

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SAMENVATTING

U. LILJENQVIST, L. HACKENBERG, T. LINK, H. HALM. Vergelijkende studie van de pull-out weerstand van pediculaire schroeven en pediculaire of laminaire haken ter hoogte van de dorsale wervelzuil.

Het is bewezen dat pediculaire schroeven ter hoogte van de lumbale wervelzuil beter weerstand bieden aan pull-out krachten, maar over het gedrag van schroeven ten opzichte van haken is weinig gekend ter hoogte van de dorsale wervelzuil.

Een in vitro-studie werd ondernomen, waarbij de axiale pull-out weerstand werd gemeten van pediculaire schroeven ten opzichte van pediculaire en laminaire haken in de dorsale wervelzuil, en dit met het oog op heelkundige scoliosiscorrectie.

De studie werd verricht op de gedesarticuleerde thoracale wervelzuil van negen kadavers. Standaard pediculaire haken werden geplaatst tussen D4 en D8 en supralami-

naire haken tussen D9 en D12, precies zoals bij een typische scoliosis instrumentatie, en werden getest tegen pediculaire schroeven. De pediculaire schroeven werden getest loodrecht op hun as ; de haken loodrecht op de geplande staafrichting. Er werden in totaal 90 pull-out testen uitgevoerd.
De gemiddelde pull-out weerstand van pediculaire schroeven was aanzienlijk hoger dan die van haken (thv D4-D8 : 531 N versus 321 N en thv D9-D12 : 807 N versus 600 N, $p < 0.05$). Bij de schroeven waren zowel diameter als botdensiteit bepalend voor de pull-out weerstand.
Bij scoliosis correctie lijkt dus het gebruik van pediculaire schroeven een nuttige bijdrage, zeker voor rechts thoracale curvaturen, omwille van het feit dat hun weerstand tegen axiale pull-out veel hoger ligt dan voor pediculaire of supralaminaire haken.

RÉSUMÉ

U. LILJENQVIST, L. HACKENBERG, T. LINK, H. HALM. Étude comparative de la résistance à l'arrachement des vis pédiculaires et des crochets pédiculaires et lamaires au niveau du rachis dorsal.

Les vis pédiculaires ont fait la preuve de leur supériorité sur le plan biomécanique au niveau du rachis lombaire; on connaît moins la résistance à l'arrachement des vis pédiculaires et des crochets au niveau du rachis dorsal. Les auteurs ont réalisé une étude biomécanique in vitro pour comparer la résistance à l'arrachement sous traction axiale des vis pédiculaires et des crochets lamaires au niveau du rachis dorsal dans des conditions correspondant à leur utilisation dans la chirurgie de la scoliose.
L'étude a été réalisée sur 9 rachis humains prélevés sur le cadavre et désarticulés. Pour reproduire les conditions d'une instrumentation postérieure segmentaire telle que réalisée dans la scoliose, des crochets pédiculaires standards ont été utilisés entre T4 et T8 et des crochets supra-lamaires entre T9 et T12 ; leur résistance à l'arrachement a été comparée à celle de vis pédiculaires. Les vis pédiculaires ont été soumises à des forces de traction axiale. Les crochets ont été soumis à des forces de traction perpendiculaires à la direction prévue pour la tige longitudinale de l'instrumentation. Un total de 90 tests d'arrachement a été réalisé.
Les auteurs ont noté que la valeur moyenne de la résistance à l'arrachement des vis pédiculaires était significativement plus élevée que celle des crochets (T4-T8 : 531 N contre 321 N, T9-T12 : 807 N contre 600 N, $p < 0.05$). En ce qui concerne les vis, ils ont observé que la résistance à l'arrachement était influencée de façon significative par le diamètre des vis et par la densité minérale osseuse.
Dans la correction chirurgicale d'une scoliose, les vis pédiculaires pourraient ainsi être intéressantes, en particulier pour des courbures thoraciques rigides, puisque leur résistance à la traction axiale est significativement-plus élevée que celle des crochets aussi bien pédiculaires que lamaires.