Clinically relevant complications related to pedicle screw placement in thoracolumbar surgery and their management: a literature review of 35,630 pedicle screws

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Object. The technique of pedicle screw insertion is a mainstay of spinal instrumentation. Some of its potential complications are clinically relevant and may require reoperation or further postoperative care.

Methods. A literature search was performed using MEDLINE (between 1999 and June 2011) for studies on pedicle screw placement in thoracolumbar surgery. The authors included randomized controlled trials, case-control studies, and case series (≥ 20 patients) from the English-, German-, and French-language literature. The authors assessed study type, the number of patients, the anatomical area, the number of pedicle screws, duration of follow-up, type of pedicle screw placement, incidence of complications, and type of complication. The management of specific complications is discussed.

Results. Thirty-nine articles with 46 patient groups were reviewed with a total of 35,630 pedicle screws. One study was a randomized controlled trial, 8 were case-control studies, and the remaining articles were case series. Dural lesions and irritation of nerve roots were reported in a mean of 0.18% and 0.19% per pedicle screws, respectively. Thirty-two patients in 10 studies (of 5654 patients from all 39 studies) required further revision surgeries for misplaced pedicle screws causing neurological problems. None of the analyzed studies reported vascular complications, and only 2 studies reported visceral complications of clinical significance.

Conclusions. Pedicle screw placement in the thoracolumbar region is a safe procedure with an overall high accuracy and a very low rate of clinically relevant complications. (DOI: 10.3171/2011.7.FOCUS11168)

Key Words • pedicle screw • misplaced screw • neurological complication • thoracolumbar surgery • management

Pedicle screw placement is a well-known and increasingly performed technique used to achieve fixation and fusion in thoracolumbar surgery. Since its first introduction by Harrington and Tullos in 1969,18 and further development by Roy-Camille et al.,53 Louis,39 and Steffee et al.38 in the late 1980s, it has become the mainstay of spinal instrumentation. This technique is used for degenerative, neoplastic, infectious, and malformative pathologies associated with axial instability. Despite technical advances over the last few decades, pedicle screw insertion is still associated with a risk of complications. Among them, the most commonly reported complication is screw malpositioning, with an overall incidence of 0%–42% in the literature.19,42 Fortunately, more serious screw-related complications, such as neurological, visceral, or vascular, are very rare.36,44,61 However, it is unclear whether the low reported numbers are due to a low incidence of serious complications or whether they are subject to underreporting due to authors’ medicolegal considerations. Although pedicle screw accuracy remains a challenge for the spine surgeon, a misplaced screw does not necessarily have clinical consequences. Thus far, we can distinguish clinically relevant from asymptomatic screw-related complications. The first ones are defined as screw complications leading to a new neurological deficit, to new radicular pain, to vascular or visceral injury, or ones that require revision surgery. Therefore, the primary research objective for this literature review was to investigate clinically relevant screw-related complications after surgical intervention in the thoracolumbar spine.

Methods

We conducted a literature review of the literature containing pedicle screw placement in thoracolumbar surgery. The abstracts and titles of all articles in MEDLINE (between 1999 and June 2011) were searched for

Abbreviation used in this paper: PMMA = polymethylmethacrylate.
pedicle screw with each of the following keywords: complications, neurological, vascular, visceral, and outcome. We only included randomized controlled trials, case-control studies, and case series (≥20 patients) in the English-, German-, and French-language literature. We only took into consideration series with adult study populations and with reported neurological or nonneurological complications in which the percentage of complications per pedicle screw or at least per patient could be extracted. Additionally, a review of all cross-references from these identified articles was performed. From the qualifying articles, the following parameters were collected: study type, number of patients, anatomical area (thoracic, lumbar, or both), number of pedicle screws, duration of follow-up, type of pedicle screw placement, incidence of complications, and type of complication. Finally, the management of screw-related complications is also discussed in detail.

Results

The literature review identified 130 possible relevant publications. After application of inclusion criteria, a total of 39 articles were selected for review: 1 randomized controlled trial, 8 case-control studies, and 30 case series (Table 1). Seven studies had different patient groups with alternative treatment options. Three studies were prospective, 25 were retrospective, and 1 study was both pro- and retrospective. Seventeen studies reported a follow-up (mean follow-up 19.0 months, range 1–118 months). The 39 studies with a total of 46 study groups included 5654 patients with 35,630 pedicle screws inserted. The indication for surgery included a singular etiology for only 13 studies (trauma, 3; scoliosis, 5; degenerative, 4; and other, 1). The remaining studies included patients with multiple pathologies: degenerative (n = 27 of the reported 46 study groups), neoplasm (in 14 study groups), trauma (in 15 study groups), infectious (in 8 study groups), scoliosis (in 10 study groups), listhesis (in 10 study groups), and others (in 13 study groups). From 2 studies, the exact etiology was not apparent from the article. Pedicle screw placement was performed free-hand in 11 studies, fluoroscopically guided in 16, navigated in 17, and robot-assisted in 2. Twenty-eight studies described the postoperative pedicle screw accuracy, with a mean percentage of 92.2% (range 67.8%–99.3%) being judged as correctly placed according to the authors. However, different classifications for pedicle screw accuracy have been used, making comparison between studies difficult.

Neurological complications were classified as dural lesions, nerve root irritation, or other neurological complication according to the authors’ descriptions. Dural lesions were reported in 36 study groups, with a mean incidence of 0.18% per pedicle screw (range 0.0%–2.0%). Di Silvestre et al. reported a dural lesion in 14 cases (12.2% of patients); all were asymptomatic. How many of all reported dural lesions led to a clinically significant complication was difficult to ascertain based on the available articles. A further analysis revealed that 9 patients in 5 studies suffered from a clinically relevant dural lesion (estimated incidence of 0.16% per patient [9 of 5654]).

<table>
<thead>
<tr>
<th>Study</th>
<th>Type of Complication</th>
<th>Incidence (range)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dural lesion</td>
<td>0.18% (0.0%–2.0%)</td>
<td>Di Silvestre et al.</td>
</tr>
</tbody>
</table>

Discussion

The ideal pedicle screw should have a maximum diameter and length without breaching the pedicle’s cortical layer or that of the vertebral body, and it should converge. Nevertheless, a satisfactory outcome can also be achieved despite suboptimal screw placement and versa (Fig. 1). For example, a screw that just barely touches the lower border of the pedicle may cause a clinically apparent radiculopathy and it may require revision. On the other hand, a screw that lies inside the spinal canal may produce no symptoms at all. Scoring systems such as the one proposed by Gertzbein and Robbins measure the cortical breach of a pedicle by a screw and are practical to compare technical methods in terms of accuracy, but have limitations. For example, a screw that lies in the inferior or medial border of the pedicle has a greater chance
### TABLE 1: Publications analyzed

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Pts</th>
<th>No. of Pedicle Screws</th>
<th>Type of Screw Placement</th>
<th>FU (mos)</th>
<th>Accuracy (%)</th>
<th>Dural Lesion (per screw)</th>
<th>Nerve Root Irritation (per screw)</th>
<th>Other Neuro Complications (per screw)</th>
<th>No. of Revs</th>
<th>Clinically Relevant Screw-Related Complication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amato et al., 2010</td>
<td>102</td>
<td>424</td>
<td>fluoro</td>
<td>8.0</td>
<td>92.2</td>
<td>0.47</td>
<td>0.47</td>
<td>1.70</td>
<td>7</td>
<td>2 pts w/ radicular pain &amp; neuro deficits (improved completely after reop), 5 pts complained of radicular pain only</td>
</tr>
<tr>
<td>Amiot et al., 2000</td>
<td>100</td>
<td>544</td>
<td>fluoro</td>
<td>6.0</td>
<td>NR</td>
<td>0.00</td>
<td></td>
<td></td>
<td>7</td>
<td>4 pts w/ long-term neuro deficits (2 probably due to incorrectly placed screws); 5 pts had nerve root irritation, 7 pts had sensomotor deficit</td>
</tr>
<tr>
<td>Arand et al., 2001</td>
<td>21</td>
<td>71</td>
<td>navig</td>
<td>NR</td>
<td>NR</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Beck et al., 2009</td>
<td>95</td>
<td>414</td>
<td>FH</td>
<td>NR</td>
<td>78.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Bledsoe et al., 2009</td>
<td>34</td>
<td>150</td>
<td>navig</td>
<td>10.0</td>
<td>93.3</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Boachie-Adjei et al., 2000</td>
<td>50</td>
<td>282</td>
<td>FH</td>
<td>NR</td>
<td>NR</td>
<td>0.00</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Carbone et al., 2003</td>
<td>22</td>
<td>126</td>
<td>fluoro</td>
<td>10.0</td>
<td>NR</td>
<td>0.00</td>
<td>0.00</td>
<td>NR</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Devito et al., 2010</td>
<td>635</td>
<td>3271</td>
<td>robot</td>
<td>NR</td>
<td>98.0</td>
<td>0.00</td>
<td>NR</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Di Silvestre et al., 2007</td>
<td>115</td>
<td>1035</td>
<td>fluoro</td>
<td>48.0</td>
<td>NR</td>
<td>0.00</td>
<td>0.00</td>
<td>NR</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Girardi et al., 1999</td>
<td>35</td>
<td>330</td>
<td>navig</td>
<td>NR</td>
<td>NR</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Iampreechakul et al., 2011</td>
<td>62</td>
<td>363</td>
<td>navig</td>
<td>NR</td>
<td>95.6</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
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<tr>
<td>Ikeda et al., 2010</td>
<td>85</td>
<td>326</td>
<td>navig</td>
<td>NR</td>
<td>98.5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Karapinar et al., 2008</td>
<td>98</td>
<td>640</td>
<td>FH</td>
<td>42.2</td>
<td>94.2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Katonis et al., 2003</td>
<td>112</td>
<td>658</td>
<td>FH</td>
<td>35.0</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td>0</td>
<td>1 pt had a neuro deficit (partial bilat drop foot after reduction of L4–5 spondylolisthesis that recovered completely after 6 wks)</td>
</tr>
<tr>
<td>Kim et al., 2004</td>
<td>394</td>
<td>3204</td>
<td>FH</td>
<td>NR</td>
<td>93.8</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Kotani et al., 2007</td>
<td>25</td>
<td>81</td>
<td>fluoro</td>
<td>NR</td>
<td>89.0</td>
<td>4.00</td>
<td>0.12</td>
<td></td>
<td>1</td>
<td>L-3 weakness &amp; pain that resolved after screw removal</td>
</tr>
<tr>
<td>Kotil &amp; Bilge, 2008</td>
<td>68</td>
<td>368</td>
<td>FH</td>
<td>NR</td>
<td>93.5</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Kuntz et al., 2004</td>
<td>29</td>
<td>209</td>
<td>fluoro</td>
<td>11.9</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Laine et al., 2000</td>
<td>50</td>
<td>277</td>
<td>fluoro</td>
<td>NR</td>
<td>86.6</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Lehman et al., 2007</td>
<td>60</td>
<td>1023</td>
<td>FH</td>
<td>NR</td>
<td>89.5</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Lekovic et al., 2007</td>
<td>25</td>
<td>183</td>
<td>navig</td>
<td>NR</td>
<td>91.3</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Lim et al., 2005</td>
<td>78</td>
<td>231</td>
<td>navig</td>
<td>NR</td>
<td>95.5</td>
<td>2.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

(continued)
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<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Pts</th>
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<th>Accuracy (%)</th>
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<th>Nerve Root Irritation (per screw)</th>
<th>Other Neuro Complications (per screw)</th>
<th>No. of Revs</th>
<th>Clinically Relevant Screw-Related Complication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lonstein et al., 1999</td>
<td>875</td>
<td>4790</td>
<td>fluoro</td>
<td>36.0</td>
<td>NR</td>
<td>0.10</td>
<td>NR</td>
<td>NR</td>
<td>7</td>
<td>8 screws removed (resolving the neuro problem in 7), 1 pt w/ residual weakness; 11 screws in 9 pts caused nerve root irritation</td>
</tr>
<tr>
<td>Lotfinia et al., 2010</td>
<td>53</td>
<td>247</td>
<td>FH</td>
<td>6.0</td>
<td>67.8</td>
<td>NR</td>
<td>NR</td>
<td>3.24</td>
<td>NR</td>
<td>2 of 3 pts w/ neuro deficit had completely recovered motor or sensory function after screw replacement</td>
</tr>
<tr>
<td>Nakashima et al., 2009</td>
<td>67</td>
<td>150</td>
<td>navig</td>
<td>NR</td>
<td>92.7</td>
<td>2.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1</td>
<td>2 nerve root injuries w/o motor deficit, 1 of these pts had a permanent numbness in S-1 area, the 2nd had LE pain</td>
</tr>
<tr>
<td>Nottmeier et al., 2009</td>
<td>220</td>
<td>1084</td>
<td>navig</td>
<td>6.0</td>
<td>92.5</td>
<td>0.18</td>
<td>NR</td>
<td>0.18</td>
<td>1</td>
<td>2 symptomatic suboptimal screw placement; 1) LE paraplegia w/ sensory preservation, 2) progressive unilat LE numbness &amp; weakness of quadriceps muscle, 3) unilat LE radicular pain w/ associated paresthesia, numbness, &amp; weakness</td>
</tr>
<tr>
<td>Parker et al., 2011</td>
<td>964</td>
<td>6816</td>
<td>FH</td>
<td>NR</td>
<td>98.3</td>
<td>0.66</td>
<td>NR</td>
<td>0.04</td>
<td>3</td>
<td>3 symptomatic suboptimal screw placement: 1) LE paraplegia w/ sensory preservation, 2) progressive unilat LE numbness &amp; weakness of quadriceps muscle, 3) unilat LE radicular pain w/ associated paresthesia, numbness, &amp; weakness</td>
</tr>
<tr>
<td>Pechlivanis et al., 2009</td>
<td>31</td>
<td>133</td>
<td>robot</td>
<td>NR</td>
<td>93.5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>2 nerve root injuries w/o motor deficit, 1 of these pts had a permanent numbness in S-1 area, the 2nd had LE pain</td>
</tr>
<tr>
<td>Rampersaud &amp; Lee, 2007</td>
<td>24</td>
<td>204</td>
<td>fluoro</td>
<td>NR</td>
<td>96.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>2 nerve root injuries w/o motor deficit, 1 of these pts had a permanent numbness in S-1 area, the 2nd had LE pain</td>
</tr>
<tr>
<td>Ravi et al., 2011</td>
<td>41</td>
<td>161</td>
<td>navig</td>
<td>6.0</td>
<td>88.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>2 nerve root injuries w/o motor deficit, 1 of these pts had a permanent numbness in S-1 area, the 2nd had LE pain</td>
</tr>
<tr>
<td>Schnake et al., 2004</td>
<td>44</td>
<td>211</td>
<td>navig</td>
<td>NR</td>
<td>95.8</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>2 nerve root injuries w/o motor deficit, 1 of these pts had a permanent numbness in S-1 area, the 2nd had LE pain</td>
</tr>
<tr>
<td>Silbermann et al., 2011</td>
<td>30</td>
<td>152</td>
<td>FH</td>
<td>NR</td>
<td>94.1</td>
<td>0.00</td>
<td>0.66</td>
<td>NR</td>
<td>1</td>
<td>1 transient paraparesis due to delayed epidural hematoma because of medial perforation, 1 pneumothorax</td>
</tr>
<tr>
<td>Stoffel et al., 2010</td>
<td>37</td>
<td>187</td>
<td>navig</td>
<td>NR</td>
<td>99.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>1 transient paraparesis due to delayed epidural hematoma because of medial perforation, 1 pneumothorax</td>
</tr>
<tr>
<td>Suk et al., 2010</td>
<td>100</td>
<td>514</td>
<td>fluoro</td>
<td>15.0</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>3</td>
<td>1 transient paraparesis due to delayed epidural hematoma because of medial perforation, 1 pneumothorax</td>
</tr>
<tr>
<td>Wang &amp; Murmaneni, 2010</td>
<td>462</td>
<td>4604</td>
<td>fluoro</td>
<td>24.0</td>
<td>98.5</td>
<td>0.07</td>
<td>0.02</td>
<td>0.09</td>
<td>1</td>
<td>1 transient paraparesis due to delayed epidural hematoma because of medial perforation, 1 pneumothorax</td>
</tr>
<tr>
<td>Wang et al., 2010</td>
<td>23</td>
<td>218</td>
<td>fluoro</td>
<td>13.4</td>
<td>NR</td>
<td>0.00</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td>1 transient paraparesis due to delayed epidural hematoma because of medial perforation, 1 pneumothorax</td>
</tr>
<tr>
<td>Wendl et al., 2003</td>
<td>30</td>
<td>141</td>
<td>navig</td>
<td>NR</td>
<td>99.3</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>1 transient paraparesis due to delayed epidural hematoma because of medial perforation, 1 pneumothorax</td>
</tr>
<tr>
<td>Youkilis et al., 2001</td>
<td>52</td>
<td>224</td>
<td>fluoro</td>
<td>NR</td>
<td>97.8</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>1 transient paraparesis due to delayed epidural hematoma because of medial perforation, 1 pneumothorax</td>
</tr>
<tr>
<td>Yue et al., 2002</td>
<td>32</td>
<td>252</td>
<td>fluoro</td>
<td>22.0</td>
<td>NR</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>1 transient paraparesis due to delayed epidural hematoma because of medial perforation, 1 pneumothorax</td>
</tr>
</tbody>
</table>

* Accuracy = percentage of screws regarded as correctly placed; FH = free-handed; fluoro = fluoroscopically guided; FU = follow-up; LE = lower-extremity; navig = navigated; neuro = neurological; NR = not reported; pt = patient; robot = robot-assisted; Revs = Revision operations due to neurological complications.
Screw-related complications in thoracolumbar surgery

Fig. 1. Computed tomography scan from our own patient series showing a medially misplaced screw in the thoracic spine. In that case, the patient had a normal neurological examination, so the screw was not revised.

of producing neurological symptoms, but it will have the same grade as a screw that lies slightly superior or lateral. Thus, scoring systems should be regarded as a tool and not as a surrogate outcome measure. Therefore, the evaluation of successful fusion surgery should always include a clinical assessment in addition to an appraisal of screw position.

Nevertheless, the accuracy of screw insertion has become a frequent topic of recent publications on spine surgery.23,28,30,36,44,59,61 A recent meta-analysis with 130 studies involving a total of 37,337 pedicle screws by Kosmopoulos and Schizas28 found a mean misplacement rate of 8.7%. Furthermore, additional surgical procedures may be required to repair injuries related to screw problems, with a mean incidence of up to 20.8%.

Different techniques have been proposed to improve accuracy, including standard fluoroscopy guidance, computer or robotic assistance, navigation systems, or specific pedicle tools as PediGuard (Spine Vision SA).32 The introduction of these techniques has led to a drastic reduction in screw misplacement rates, mainly in difficult cases such as scoliosis or revisions.28

Nonetheless, experienced spine surgeons have shown the ability to insert screws in the thoracolumbar region with a low incidence of screw misplacement simply by respecting the anatomical landmarks.26 Furthermore, navigation or robotic systems present limitations related to calibration errors, bending of instruments, occasional blocking of the camera field of view, inadvertently touching/hitting reference frames, and nonrigid connection between the reference base and the actual surgical site. This review of the literature clearly shows that the accuracy rate of pedicle screws in thoracolumbar surgery is around 92.2%. However, the findings of this study confirmed that clinically relevant complications related to screw misplacement are very rare and occur in less than 0.5% of all procedures. This is in line with the findings from Lonstein et al.,36 who reported in their meta-analysis of 4790 pedicle screws a breach rate of 5.1%, with no more than 0.2% of them causing neurological symptoms.

Management of Screw-Related Complications

As for every complication, the best treatment is prevention. Perfect anatomical knowledge, respect of all anatomical landmarks, careful evaluation of preoperative images, and use of modern systems of surgical assistance may reduce the risk of screw misplacement. Moreover, various methods (for example, intraoperative fluoroscopy, PediGuard, navigation systems, or specific pedicle tools as PediGuard (Spine Vision SA), O-Arm) can be used to confirm the pilot holes and the screw position during surgery. Furthermore, screw placement can be electrophysiologically checked during surgery by stimulating the pedicle probe or the screw and obtaining an electromyographic response peripherally. If this response occurs below the normal threshold for the intact cortical bone, it is highly probable that the screw is outside of the pedicle and needs to be replaced.47 Although minor misplacement poses little risk of injury, a displacement greater than 4 mm is associated with a high risk of injury to vital structures depending on the instrumented level.48

Nerve Root or Spinal Cord Injury. The overall incidence of nerve root or spinal cord injury is rare, ranging between 0.6% and 11%.40 Our study showed an overall mean incidence of dural lesions of 0.18% per pedicle screw and an overall mean incidence of nerve root irritations of 0.19% per pedicle screw (Fig. 2). Although a transitory self-limiting neurapraxia is more common, the incidence of a permanent neurological deficit is rare. Pihlajamaki et al.50 found a permanent foot drop in 3 of 102 patients, which was only attributable to screw misplacement in 1 of the patients. A new neurological deficit or a new postoperative pain requires careful evaluation of postoperative images to rule out a conflict with a screw, in which case surgical revision is necessary. The planning of the revision procedure should be as complete and precise as possible, because a second misplacement will not be acceptable. A new trajectory within the pedicle should be planned, according to the previous entry point and the target. During the procedure, the misplaced screw is exposed and removed. In such cases, the application of intraoperative CT scanning or navigation is recommended. The new trajectory within the pedicle may create a larger hole, which may cause insufficient purchase of the subsequent screw. For such cases, a rescue procedure must always be available. The surgeon can choose either a larger salvage screw or skip the level and extend the fixation to more levels. Alternatively, the purchase can be augmented by means of PMMA injection. The cement may be injected into the new trajectory and the screw rapidly inserted before cement consolidation. Nowadays, several perforated screws exist that allow for PMMA injection. Recently, self-expanding screws have been developed as well, which increase screw purchase.
Vascular Injury. Although no vascular complications were reported in the reviewed studies, it is evident that several vascular structures are in danger during pedicle screw insertion: the azygos vein, intercostal artery, inferior vena cava, and aorta for the thoracic spine and mainly the aorta and common iliac vessels for the lumbar spine (Fig. 3). Immediate recognition of a vascular injury is mandatory, because it may be fatal for the patient. A direct vascular suture or embolization can be performed in emergency situations after corresponding repositioning. The need for replacement of a misplaced screw in tight contact with a vessel in an asymptomatic patient is controversial. Some authors consider the revision procedure too risky. Foxx et al.\textsuperscript{14} found 33 of 680 inserted screws in the thoracolumbar region to be in contact with great vessels. None of the patients with vessel contact was noted to be symptomatic or presented with sequelae as a result of vessel contact. Other authors have suggested performing a revision procedure, because a secondary lesion may further develop into the site of contact between the screw and the continuously beating vessel (for example, lacerations and pseudoaneurysms). Klodell et al.\textsuperscript{27} presented a case of safe revision for aorta impingement from a pedicle screw, which was diagnosed 1 year after a thoracic stabilization. Moreover, screw removal is not always technically simple and may be associated with major complications. Vanichkachorn et al.\textsuperscript{60} presented a case of major vessel injury after removal of a distal screw fragment in the thoracolumbar region. They strongly encouraged a thorough evaluation for the indication to remove any distal screw fragment in a vertebral body. Lopera et al.\textsuperscript{35} presented a series of 6 patients with 7 arterial injuries related to misplacement of fixation screws including the thoracic aorta (in 4 cases) and common iliac arteries (in 3 cases). There was wall penetration in 5 cases, contained penetrations in 2, and vessel occlusion in 1 case. Two patients had asymptomatic impingement of the aortic wall by the screws. One patient died and another underwent limb amputation. Three patients were treated with placement of stent grafts and screw removal. Screw replacement was performed in 1 patient. Conservative observation was done in 1 patient. They concluded that vascular injuries related to misplacement of fixation screws are potential life- and limb-threatening complications that require early recognition with prompt repair of vascular lesions and screw reposition.

Cerebrospinal Fluid Leak. If a CSF leak is seen during pedicle screw insertion, it means that the screw is too medial or inferior. In such cases, direct visualization by laminectomy is necessary to suture the leak, although some CSF leaks may spontaneously resolve.\textsuperscript{13} The removal of a screw placed too medially into the neural canal is challenging because of potential neurological injury. Therefore, screw removal should always be done under direct visualization of the adjacent nervous structures. Donovan et al.\textsuperscript{12} reported a case in which a screw was previously inserted into the canal with a CSF leak. They performed a durotomy and safely removed the screw under direct visualization of the neural elements. Nakashima et al.\textsuperscript{43} reported the successful use of fibrin sealant to treat dural leaks after pedicle screw placement.

Visceral Injury. In this review, only 2 studies reported visceral complications that became clinically significant (see below). The proximity of thoracolumbar vertebral bodies and visceral organs may explain some visceral complications observed in the literature. A too long pedicle screw in thoracic region may potentially injure the esophag-
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gus, the pleura, and the lung. O’Brien et al.45 reported a case of esophageal impingement from pedicle screws at T-3. Esophagoscopy showed a discrete area of attenuation of the mucosa but no perforation. The authors revised the implant, inserting shorter screws in T3–5 levels bilaterally. Our literature review revealed only 2 visceral complications, notably a pleural effusion and a pneumothorax, that were reported after 35,630 pedicle screw placements in 5654 patients.

**Pedicle Fracture.** The overall pedicle breakage rate for lumbar fusion is around 1.1% in the literature.13 In our study, only 3 authors reported intraoperative pedicle fractures.11,36,58 This complication is the result of a mismatch between the screw size and the pedicle diameter (Fig. 4). Therefore, the right choice of screw size is mandatory, leaving the preoperative planning (pedicle diameter, pedicle angle, and screw length) of utmost importance. In young patients with a hard cancellous bone, tapping is recommended before screw insertion. Making the screw hole as large as the minor diameter of the inserted screw may avoid this complication. Once pedicle fracture occurs, the surgeon can choose an alternative method of fixation (for example, hooks) or incorporate additional levels into the fixation.

**Screw Pullout.** Screw pullout results from the loss of metal-bone interface integrity. Poor bone density (osteo- porosis), excessive strain on the implant, residual sagittal imbalance, screw hole preparation technique, torque of insertion, screw purchase, and direction of screw placement may influence the pullout strength of pedicle screws. Tapping the screw hole or additional sublaminar hooks may increase pullout strength.17 Once a screw pullout occurs, the surgeon should revise the implant. Different salvage techniques exist: using larger screws, screws with a larger thread depth and pitch, screws with bicortical purchase, milled bone graft impacted into the pilot hole, or PMMA-augmented screws. Restoring sagittal balance is mandatory to prevent new screw pullout.46,49

**Screw Breakage.** Screw breakage is mainly attributable to metal fatigue. Its incidence is reported to range from 3% to 5.7%,40 and it often occurs at the interface between the screw and the rod. It often indicates a delay in fusion or pseudarthrosis. There is a clear trend for more screw breakage in fusions that include the sacrum, in patients in whom a spondylolisthesis was reduced without anterior support, and in incompletely instrumented or multilevel fusions.22 In such cases, there is an absolute indication to revise the implant. The revision should correct the biomechanical reasons for breakage. The fusion strategy and the fixation extension should be reconsidered, and a successful union must be achieved. The constructs’ stiffness may be improved by inserting anterior devices, by switching from titanium to stainless steel, or by inserting additional cross-links to the system.46

**Late Spinal Instability.** The presence of a misplaced screw may also lead to a loss of stiffness of the implant and to a late spinal instability. Açikbas et al.1 compared 2 groups of patients: Group A (16 patients) where the screw were correctly placed, and Group B (16 patients) where at least 1 of the screws was misplaced. They evaluated bone fusion, anterior height of the fractured vertebrae, and kyphotic deformity on neutral radiographs during the postoperative period and neutral/dynamic radiographs at the long-term follow-up. Group B presented with a minor degree of deformity correction in the postoperative period, a loss of correction on long-term radiographs, and more pain than patients in Group B. In conclusion, the impact of a misplaced screw on the implant stiffness should be always analyzed. Major misplacements in a critical part of the implant (for example, the ends of the implants and junctions) should be immediately corrected. In case of minor misplacement, close radiological and clinical follow-up is mandatory.

**Conclusions**

Pedicle screw placement is a safe procedure with a very low rate of clinically relevant complications. Navigation systems may be required in complex cases as revision procedures or scoliosis or in difficult spinal levels as the upper cervicothoracic spine. Although accuracy has been improved by introduction of different image guidance systems, the surgeon’s knowledge of the anatomical landmarks, response to visual and tactile cues, and intraoperative decision making remain of paramount importance.

**Disclosure**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.
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