Methods of Segmental Screw Fixation of Axis: A Cadaveric and Surgical Study

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Abstract

Background Data: Axis fixation is still challenging due to intimate relation with the vertebral artery and complex topographical anatomy.

Purpose: The aim of this work is to assess and compare the safety, feasibility and limitations of 3 posterior segmental axis fixation techniques (transpedicular, transpars and translaminar screws).

Study Design: A retrospective anatomico-radiological study.

Material and Methods: Forty axis vertebrae (27 dry bone and 13 computed tomography scans of patients who underwent axis fixation) were retrospectively studied (total 80 sides). The morphology of the pedicle, pars interarticularis and lamina were assessed bilaterally for the width (W), height (H) and screw length (L). In addition, the spino-laminar angle was measured. It was considered difficult for a conventional 3.5mm screw to be inserted safely, if any of these parameters is ≤4.5mm.

Results: The mean pedicle, pars and lamina W and H were (6.0±1.5mm and 7.1±1.8mm), (9.51.6±mm and 192.5±mm) and (6.2±1.5mm and 12.1±1.5mm) respectively. The mean spino-laminar angle was 45.1±4° laterally. The mean transpedicular and translaminar screw lengths were 26.8±2.2 and 23±4.1mm respectively. While the feasibility rates were 83.7% and 90% because the pedicle (W and H) and laminar (W) were ≤4.5mm respectively. All the pars measured in this study can tolerate a 14mm screw. However, when using 15mm, 16mm, 17mm and 18mm screws, the incidence of violating the vertebral artery groove was 2.5%, 6.3%, 13.8% and 23.8% respectively.
Conclusion: Transpedicular screws provide the most rigid fixation (longest screws), however in case of high vertebral groove, translaminar screws are better option rather than transpars screws except in small size laminae. (2016ESJ094)

Keywords: Axis Fixation, Trans-laminar, Transpars-interarticularis, Transpedicular screws, Atlantoaxial Instability

Introduction

Axis fixation is still challenging due to intimate relation with the vertebral artery and complex topographical anatomy.\textsuperscript{1,2,21,22} So, sublaminar wires, cables and hooks were frequently used.\textsuperscript{4,6,8} However, they had lower fusion rates, necessitates intact posterior vertebral components and postoperative immobilization.\textsuperscript{6,16,23}

Transpedicular screw fixation was first pioneered in 1964 by Leconte and followed by Borne et al for treatment of traumatic spondylolisthesis (hangman’s fracture) of axis.\textsuperscript{3,11}

Trans pars interarticularis screw is a modification of Magerl C1-C2 transarticular screw,\textsuperscript{13} which is a non segmental fixation technique between C1-C2 requiring perfect preinsertion alignment of C1-2 joint for its safe placement. In contrast, trans pars screw is significantly shorter and does not transgress the C1–C2 facet joint.\textsuperscript{10}

Both transpedicular and trans pars interarticularis screws (like transarticular screw) have the potential risks of vertebral artery injury in high vertebral artery groove (VAG) which may be present unilaterally in approximately 14-18 \% of cases.\textsuperscript{2,15} Alternatively, to avoid the associated risk of vertebral artery injury, Wright described crossed translaminar screws in 2004.\textsuperscript{20}

Transpedicular, transpars interarticularis and translaminar screws provide posterior segmental fixation of axis, so each screw is inserted independently of atlas.\textsuperscript{23} In 1994, Goel and Laheri,\textsuperscript{9} revolutionized atlanto-axial fixation by using atlas lateral mass screws and axis transpedicular screws connected via plate and screw construct.

The aim of this study is to assess and compare the safety, feasibility and limitations of transpedicular, transpars and translaminar screws.

Material and Methods

Forty axis vertebrae of Egyptian population (27 dry bone) and 13 computed tomography (CT) scans of patients who underwent axis fixation) were retrospectively studied for the safety and feasibility of insertion of transpedicular, transpars or translaminar screws.

The morphology of 27 dry axis vertebrae of unknown age and sex were studied using Vernier caliper (sensitive to 0.1mm) and a goniometer for angular measures. In addition, thin slice (1 mm) CT scan of cranio-cervical junction of 13 patients who underwent posterior segmental axis fixation were also assessed (Total 80 sides).

The pedicle width (W) and the height (H) were measured at the level of the transverse foramen in dry axis and CT scan of cranio-cervical junction according to Abou Madawi et al,\textsuperscript{2} and Wang et al,\textsuperscript{19} respectively (Figure 1). The entry point of transpedicular screw was located at the lateral aspect of the C-2 lateral mass, just caudal to the transition of the lateral mass into the C-2 pars,\textsuperscript{17} with angulation of (25-40°) medially and (15°20°) rostrally as described by Sciubba et al,\textsuperscript{17} (Figure 2). The transpedicular screw length (L) was calculated from the entry point to the anterior cortex of axis body.
The pars (W) and length (L) of transpars screw trajectory were calculated from an entry point 3mm rostral to the inferior edge of the C-2 lateral mass with about 60° rostral angulation and stops without violating the VAG the C1-2 joint as described by Hoh et al,\(^{10}\) (Figure 1,2).

Regarding translaminar screws, the minimal (W) and (H), in addition to the length (L) of C2 laminar screw from the entry point (5-6mm posterior to the post-edge of the spinal canal) to the lateral rim of lamina at the junction with the lateral mass following the slope of lamina;\(^{25}\) and the spino-laminar angle (A°) were measured bilaterally as described by Cassinelli et al,\(^{5}\) (Figure 2,3).

According to Wang et al,\(^{19}\) if the pedicle (w) and (H) were ≤4.5mm, it was considered difficult for a conventional 3.5mm transpedicular screw to be inserted safely. This convention was applied to the translaminar screws, if the laminar (W) ≤4.5mm and ≤5mm was used as cut off for translaminar screws as in transpedicular screws, the feasibility of safe insertion of translaminar screws was 90%.

The overall mean pars interarticularis W and H were 9.51.6±mm and 19.2±mm respectively (Table 1). In contrast to the transpedicular and translaminar screws where the width of the pedicle and lamina is a limiting factor for screw insertion, the height of the pars interarticularis a limiting factor. All the pars measured in this study can tolerate a 14mm screw because their length was ≥14mm. However, when using 15mm, 16mm, 17mm and 18mm screws, the incidence of violating the VAG was 2.5%, 6.3%, 13.8% and 23.8% respectively (Figure 4).

It is worth mentioning that there was no significant difference of each parameter between the left and right sides of the pedicle, pars and lamina (P >0.05).

Out of 13 patients who underwent axis fixation and their CT scan were measured in this study, 11 patients had atlanto-axial instability of various causes (10 patients underwent atlas lateral mass screws and one of the 3 segmental axis screw fixation techniques (Figure 5,6) and one patient had occipito-axis fixation) and 2 patients had traumatic spondylolisthesis of axis (underwent C2-C3 fixation) (Figure 7).
**Figure 1.** Computed tomography scan of a patient with high vertebral artery groove on the left side (A) Axial view showing Lt narrow pedicle width of 2.79mm only, (B) coronal view showing Lt small pedicle height of 2.74mm only, (C) sagittal view showing the trajectory and entry point of transpars interarticularis screw.

**Figure 2.** The trajectories and the entry points of the 3 posterior segmental axis screws (A) 1: the transpedicular screws, 2 and 3 the crossed laminar screws (note that they are not at the same level), 4 the trans pars interarticularis screw (stopping at the superior facet). (B) the crossed laminar screws

**Figure 3.** (A) Superior view of dry axis vertebra showing the minimal width of lamina (W) and the length of crossed translaminar screw inserted from Rt side in the Lt lamina with lateral angulation A°, (B) posterior view of the same axis vertebra showing the minimal height of the lamina (H).
Figure 4. The percentage of vertebral artery groove violations at different trans pars screw lengths. Y axis indicates the percentage of patients and X axis indicates transpars screw length.

Figure 5. Postoperative CT scan of 2 patients with atlantoaxial fixation; A) axial and B) sagittal views of transpedicular screws of 25 mm length; C) axial and D) sagittal views of transpars interarticularis screws of 14mm length.

Figure 6. Postoperative imaging of a patient with atlantoaxial fixation who underwent crossed translaminar screw fixation of axis. A) Plain x-ray lateral view; B) axial CT scan.
Discussion

For thirty years, transpedicular screw fixation was used only for treatment of traumatic spondylolisthesis (hangman’s fracture) of axis since its first description by Leconte11 in 1964. However, posterior segmental screw fixation of axis has been widely used for atlanto-axial instability after Goel and Laheri,9 introduced atlas lateral mass screws in 1994.

There is confusion regarding the terminology and the differentiation between the C2 pars interarticularis and the pedicle which arises from the anatomical confusion. The C2 pars interarticularis (isthmus) is present between the superior and inferior articular processes covering the pedicle completely from posterior view, and the pedicle is the structure beneath the C-2 isthmus which connects the lateral mass–inferior articular process to the body of the axis. So, the term trans pediculosthmic screw fixation is more appropriate than transpedicular screw fixation because the screw.

**Table 1.** Different Morphological Parameters Used for Pedicle, Pars Interarticularis and Lamina.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rt (N=40)</th>
<th>Lt (N=40)</th>
<th>Bilateral (N=80)</th>
</tr>
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<tbody>
<tr>
<td><strong>Pedicle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W mm</td>
<td>6.1±1.5</td>
<td>5.9±1.6</td>
<td>6.0±1.5</td>
</tr>
<tr>
<td>H mm</td>
<td>7.2±1.9</td>
<td>7±1.5</td>
<td>7.1±1.8</td>
</tr>
<tr>
<td>Screw L mm</td>
<td>26.9±2.3</td>
<td>26.6±2</td>
<td>26.8±2.2</td>
</tr>
<tr>
<td><strong>Pars inter-articularis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W mm</td>
<td>9.5±1.9</td>
<td>9.6±1.4</td>
<td>9.5±1.6</td>
</tr>
<tr>
<td>Screw L mm</td>
<td>19.1±2.4</td>
<td>18.9±2.6</td>
<td>19±2.5</td>
</tr>
<tr>
<td><strong>Lamina</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screw L mm</td>
<td>23.2±3.8</td>
<td>22.9±4.6</td>
<td>23±4.1</td>
</tr>
<tr>
<td>H mm</td>
<td>11.9±1.7</td>
<td>12.1±1.4</td>
<td>12.1±1.5</td>
</tr>
<tr>
<td>W mm</td>
<td>6.1±1.5</td>
<td>6.2±1.4</td>
<td>6.2±1.5</td>
</tr>
<tr>
<td>A°</td>
<td>45±6.9°</td>
<td>45.1±3.7°</td>
<td>45.1±4°</td>
</tr>
</tbody>
</table>

**Figure 7.** A patient with traumatic spondylolisthesis (hangman’s fracture) of axis. (A) preoperative sagittal CT scan, (B) postoperative lateral x-ray showing good reduction of the C2 displacement over C3 after C2-3 fixation, (C) intraoperative image showing the fracture of pars bilaterally (white arrows), (D) intraoperative image after fixation (C2 Lt transpedicular and Rt trans pars while C3 was fixed via 2 lateral mass screws)
passes through the pars before the pedicle to reach the vertebral body of axis.\textsuperscript{14}

Transpedicular screws provide the most biomechanically rigid axis fixation.\textsuperscript{12} The average reported transpedicular screw length ranges from 25mm to 31mm,\textsuperscript{3,9,17,18,23} which is consistent with the mean screw length in this study (26.8±2.2mm). However, the reported incidence of transpedicular screws breach was approximately 15-20% and the majority occurring laterally towards VAG,\textsuperscript{17,24} which may be due to thinner lateral wall of the C-2 pedicle compared to the medial wall.\textsuperscript{7} The major hazard of transpedicular screws is the risk of vertebral artery injury in high arched VAG which may be present unilaterally in approximately in 14-18% of population.\textsuperscript{15,19}

The pars interarticularis screws are also placed in the C-2 lateral mass and continue through the pars interarticularis, but stop short of the pedicle and the transverse foramen.\textsuperscript{10,23} Therefore, the risk of vertebral artery injury is less than transarticular screws and transpedicular screws. The potential for vertebral artery injury would occur with an excessively long C-2 pars screw that over penetrates the transverse foramen.\textsuperscript{10}

All the 80 pars interarticularis measured in this study can accommodate a 14mm screw safely. However, 15mm, 16mm, 17mm and 18mm screws can be tolerated in 97.5%, 93.7%, 86.2% and 76.2% respectively. These results are consistent with the results of Hou et al,\textsuperscript{10} study of 100 pars who noted that 99%, 95% and 84% of studied pars can accommodate 14mm, 16 mm and 18 mm screws.

On the other hand, the risk of vertebral artery injury during translaminar screw insertion was eliminated if the screw stopped at the junction between the lamina and the lateral mass. The screws can be inserted without breaching into spinal canal if the angle of insertion is ≥50° laterally. The reported maximum safe length of translaminar screws ranged from 21mm to 28mm,\textsuperscript{21,23,25} which is slightly shorter than the transpedicular screws but significantly longer than trans pars screws. However, the recent radiological and cadaveric studies reported that the width of C2 lamina was <5mm in 15-29% of cases.\textsuperscript{5,21} Consistent with these reports, the width of C2 lamina was ≤4.5mm and <5mm in 10% and 16.3% respectively.

Lehman et al,\textsuperscript{12} compared the biomechanical stability of the three posterior segmental axis screws and reported that transpedicular screws provide the strongest fixation for both initial and salvage situations. If they should fail, translaminar screws provided stronger and more reproducible fixation than transpars screws.

In summary, the 3 posterior segmental axis fixation techniques are valuable tools for axis fixation in case of atlantoaxial instability (combined with atlas lateral mass screws) providing superior biomechanical stability and higher fusion rates than traditional wiring techniques. However each technique has its advantages and limitations. Transpedicular screws can also be used in traumatic spondylolisthesis of axis and provide the longest screw trajectory, however it is limited by high arched VAG. The translaminar screws are simple and provide long screw next to transpedicular screws and avoid the risk of vertebral artery injury, however they are limited by small laminar size in few cases and not possible after laminectomy. The transpars screws are simple and beneficial in case of high VAG associated with small lamina but they are shorter and inferior biomechanically than the other two techniques.
Conclusion

Transpedicular screws provide the most rigid axis fixation (longest screws), however in case of high vertebral artery groove, translaminar screws are better option rather than transpars screws except in small size lamina or previous laminectomy.

References


طرق تثبيت فقرة المحور بواسطة البراغي، دراسة تشريحية وجراحية

البيانات الأساسية: تثبيت الفقرة العنقية الثانية لا يزال صعب بسبب العلاقة الحميمة مع الشريان الفقري والتشريح الطبوغرافي المعقد.

الغرض: تهدف هذه الدراسة لتقييم وropolتة reluctance وصلاحية وقصور 3 أنواع من البراغي المستخدمة لتثبيت فقرة المحور خلفياً.

تصميم الدراسة: دراسة تشريحية وجراحية.

المريض و الطرق: قياس أبعاد الفقرة العنقية الثانية المرتبطة بالتثبيت الفقري والشريان الفقري.

النتائج: بعد دراسة 40 فقرة، كان متوسط عرض وارتفاع العنقية والبرزخ والصفيحة (1 ± 0.1 مم و 1.8 ± 0.1 مم). كان متوسط أطوال البراغي الممكن تركيبها في العنقية والصفيحة (7.8 ± 1 مم و 1.9 ± 1 مم)، بينما احتمل البرزخ تماماً براغي بطول 14 مم. و لكن عند استخدام براغي أطول حدث انتهاك لأخدور الشريان الفقري.

الاستنتاج: نستنتج من ذلك أن تثبيت المحور بواسطة البراغي العنقية أكثر ثباتاً حيث أنه الأكثر طولاً، ولكن في حالة ارتفاع الأخدور الشريان الفقاري فإن براغي الصفيحة أفضل.