Percutaneous fixation of thoracolumbar fractures: Current concepts

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Accepted: 29 September 2012

\textbf{Summary} Numerous improvements in minimally invasive spine surgery (MISS) have been made during the last decade. MISS in thoracolumbar spine trauma management must achieve the same results as conventional treatment but with less morbidity. The increased use of MISS technologies in spine trauma has been correlated to the availability of more versatile instrumentation, which makes the fixation of all thoracic and lumbar levels possible. Balloon-assisted techniques have been used to support the anterior column in a stand-alone manner or in combination with open or percutaneous pedicle screw fixation. Fluoroscopy-assisted pedicle screw insertion is associated with less pedicle wall violation when compared to open surgery, but with increased radiation exposure for the surgeon and patient. Surgeons must be aware of this issue and new technologies are available to decrease irradiation. The advantages of percutaneous pedicle screw fixation relative to open surgery are discussed: preservation of posterior musculature, less blood loss, shorter operative time, lower infection risk, less postoperative pain, shorter rehabilitation time as well as shorter hospital stay. Limitations of percutaneous fixation include the inability to achieve direct spinal canal decompression and not having the option to perform a fusion. Nevertheless, these limitations can be addressed by combining MISS with open techniques. Indications for percutaneous spine fixation alone or in combination with MISS or open techniques are discussed based on the AO classification. The benefits of percutaneous spinal fixation for unstable spine fractures in polytrauma patients are also discussed. Posterior instrumentation can be easily removed after bone union to allow young patients to regain their mobility. Large well-controlled prospective studies are needed to draw up guidelines for less invasive procedures in spine trauma. In the future, development of new technologies can expand the scope of indications and treatment possibilities using MISS techniques in spine trauma.

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Introduction

Posterior minimally invasive spine surgery has been developing steadily over the past 10 years. Minimally invasive surgery is expected to provide the same results as conventional surgery, but with less morbidity. Percutaneous
Percutaneous transverse fixation of the lumbar spine was initially developed to improve the functional results of surgery degenerative spine diseases [1]. It was then used for trauma and tumour-related conditions. Further innovations have allowed the indications to be expanded. But because percutaneous techniques are relatively new, few randomized studies have confirmed the benefits of using such techniques in spinal trauma cases.

History

Percutaneous targeting of the pedicles is not new concept. It was first described in 1977 by Magerl [2] and then Dick et al. [3] as the percutaneous placement of a spinal internal fixator to identify symptomatic disc levels before performing a fusion. This technique was abandoned because it did not provide the desired results [4]. In 2001, Foley et al. described a system that automatically placed pre-curved rods onto polyaxial pedicular screws implanted percutaneously (Fig. 1), which led to the first case of percutaneous fixation being performed for degenerative disc diseases [1]. Percutaneous targeting techniques have gradually improved and have led to the expanded use of these fixation methods [5]. However, pre-curved lordotic rods limited the application of percutaneous fixation to the lumbar region only. Instrumentation is now available that can be used to perform lumbar and thoracic fixation by placing rods that are curved freehand to the desired shape, without limitation on the number of levels instrumented (Fig. 2). Monoaxial screws can be used with this new instrumentation, allowing for more effective reduction manoeuvres (distraction, compression). But the problem with percutaneous fixation is that it is relatively fragile when fusion is not performed and transverse connectors cannot be used, especially in cases of anterior spinal column comminution with a risk of fixation failure. This fragility was addressed by performing additional corpectomy and bone grafting procedures from an anterior approach. With the arrival of intravertebral augmentation systems such as balloon kyphoplasty, the anterior spine could be reconstructed percutaneously without an additional anterior procedure in selected cases (Fig. 3). And finally, the development of new minimally-invasive approaches for the spine that can be used in combination with percutaneous fixation also allows nerve decompression and intersomatic fusion to be performed. There are now a number of techniques that can be combined to expand the indications for percutaneous fixation.

Advantages of percutaneous fixation for the spine

With an open, posterior approach, the need to detach muscles and continuously, aggressively retract them has been
implicated in muscle denervation and devascularisation, leading to muscle atrophy [6,7]. All of these events can lead to intraoperative bleeding and the need for blood transfusions, which also increase the infection risk [7–9]. These events are also one of the causes of postoperative pain and loss of muscle strength, which delays functional recovery and can result in chronic pain [6,10–12]. Multifidus muscle dysfunction has been implicated in the pathophysiology of chronic low back pain [7,11,12]. Percutaneous surgery, by sparing the paravertebral musculature, should limit bleeding, reduce infection rates and postoperative pain, which would reduce the length of hospitalisation, make rehabilitation easier and faster and could limit the destabilisation of adjacent levels over the long term.

**Muscle preservation**

In a cadaver study, Regev et al. found that the *multifidus* motor nerve was injured in 20% of cases when screws were implanted percutaneously versus 80% when the screws were implanted during an open procedure (*P* < 0.0001) [13]. In a clinical study of degenerative diseases, Kim et al. found that patients operated with an open procedure took more postoperative pain killers, had higher muscle enzyme levels on the first and seventh day, and had significantly more muscle atrophy visible on MRI [6]. Postoperative muscle strength was better preserved in the group receiving percutaneous fixation. In a preclinical sheep study, Lehmann et al. found that muscle enzyme levels did not increase as much when the screws were placed percutaneously versus open (*P* < 0.05); this was independent of the operative time [14].

**Blood loss**

Wild et al. reported statistically lower blood loss in trauma cases after the Dick et al. internal fixation was implanted percutaneously than when implanted during an open procedure [15]. Schmidt et al. described a series of 76 percutaneous long-segment fixation cases for the thoracic spine. Blood transfusion was needed only in three cases; these were all cases where an additional anterior procedure also had to be performed [16]. Merom et al. compared two groups of ten injured patients treated with either percutaneous or open fixation [17]. The average blood loss was 50 mL less in the percutaneous group than in the open group (range 200 to 500 mL) (Table 1).

**Operative time**

Merom et al. reported that with short-segment fixation, the operative time for percutaneous fixation (73 to 85 minutes) was slightly less than for open fixation (78 to 102 minutes) [17] (Table 1). Ni et al. reported an average operative time of 70 minutes for short-segment fixation [18]. In a series of 76 patients (16 with long-segment fixation), Schmidt et al. reported an average operative time of 47 minutes. In 56% of these patients, the total operative time was between 22 and 36 minutes [16].

**Infection rate**

Ni et al. reported one superficial infection out of 36 patients having percutaneous fixation; the infection was treated with antibiotics alone [18] (Table 1). Schmidt et al. had no infections in 76 patients, but one revision was performed for paravertebral haematoma [16]. Merom et al. observed only one superficial infection in ten cases of open fixation and no infections in ten cases of percutaneous fixation [17]. Palmisani et al. had one infection that required instrumentation removal out of 64 percutaneous fixation cases [20]. Overall, these published studies reported a fairly low infection rate when compared to infection rates for open procedures, which are known to be around 3.1% and can go up to 10% [8].

**Hospital stays**

In the Merom et al. study, patients treated with percutaneous fixation were able to walk one or two days after the surgery; those treated with open fixation had to wait three or four days before they could walk [17] (Table 1). Others have reported clearly shorter hospital stays after percutaneous surgery than after open surgery for trauma indications [18,22].

**Positioning of pedicle screws placed percutaneously under fluoroscopy control**

Wiesner et al. reported that in a series of 408 screws implanted percutaneously, 6.6% (27 screws) had pedicle wall violations, with two cases needing an open revision procedure because of neurological problems [23] (Table 2). They observed that many of these misplaced screws (11 of 27) occurred in the sacrum. Ringel et al. looked at the position of 488 screws: the placement was good in 87% of cases, acceptable in 10% and unacceptable in 3% [24]. Nine of the screws had to be repositioned, with two being at the origin of nerve root pain. Pelegri et al. reported a 3.8% rate of misplacement out of 50 screws; in one case, an open revision had to be performed because of neurological problems [21]. Ni et al. found that 6.7% of 104 screws implanted were misplaced, but there were no neurological complications [18]. Korovessis et al. reported that out of 180 screws implanted percutaneously for fracture fixation, three were placed too medially, but these had no clinical consequences and they occurred early in his learning process [22]. In summary, these studies show that percutaneous pedicle screw targeting with fluoroscopy guidance, when using proper technique, leads to fewer pedicle wall violations than when performed open [7].

**Limitations of percutaneous fixation**

**Exposure to X-rays**

Proper percutaneous screw placement requires a precise technique and high-quality fluoroscopy (Table 3). But the surgeon, operating suite team and patient will be exposed to ionizing radiation, which is a true concern. Screw placement requires 9.3 seconds of exposure to X-rays [25]. In a
Table 1
Comparison of published results describing intraoperative bleeding, operative time, infection rate and length of hospital stay.

<table>
<thead>
<tr>
<th></th>
<th>Intraoperative bleeding&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Operative time&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Infection rate</th>
<th>Length of hospital stay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percutaneous</td>
<td>Open</td>
<td>Percutaneous</td>
<td>Open</td>
</tr>
<tr>
<td>Wild et al. [15], n = 21</td>
<td>194 mL (100–300)</td>
<td>380 mL (100–800)</td>
<td>87 min (63–120)</td>
<td>81 min (59–118)</td>
</tr>
<tr>
<td>Merom et al. [17], n = 20</td>
<td>50 mL</td>
<td>200–500 mL</td>
<td>73–85 min</td>
<td>78–102 min</td>
</tr>
<tr>
<td>Ni et al. [18], n = 36</td>
<td>75 mL</td>
<td>NR</td>
<td>70 min</td>
<td>NR</td>
</tr>
<tr>
<td>Schmidt et al. [16], n = 76</td>
<td>1 transfusion after add. ant. procedure</td>
<td>NR</td>
<td>47 min</td>
<td>NR</td>
</tr>
<tr>
<td>Verlaan et al. [19]</td>
<td>1000 mL</td>
<td>NR</td>
<td>3.1% to 10%</td>
<td></td>
</tr>
<tr>
<td>Palmisani et al. [20], n = 64</td>
<td>NR</td>
<td>NA</td>
<td>120 min (60–240)</td>
<td>NA</td>
</tr>
<tr>
<td>Pelegri et al. [21], n = 15</td>
<td>NR</td>
<td>NA</td>
<td>108 min (40–180)</td>
<td>NA</td>
</tr>
</tbody>
</table>

N: number of patients; min: minutes; mL: millilitres; NR: not reported; NA: not applicable; add. ant: additional anterior.
<sup>a</sup> Short-segment fixation.
TABLE 2 Comparison of pedicle screw misplacement rate during percutaneous implantation in various studies.

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>n = 408</td>
<td>n = 488</td>
<td>n = 50</td>
<td>n = 104</td>
<td>n = 180</td>
</tr>
<tr>
<td>% of misplaced screws(^a)</td>
<td>6.6%</td>
<td>3%</td>
<td>3.8%</td>
<td>6.7%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Number of screws/n</td>
<td>n = 27</td>
<td>n = 14</td>
<td>n = 2/n = 9</td>
<td>n = 1/n = 1</td>
<td>n = 0/n = 0</td>
</tr>
<tr>
<td>Number of neurological problems/revisions</td>
<td>n = 2/n = 2</td>
<td>n = 2/n = 9</td>
<td>n = 1/n = 1</td>
<td>n = 0/n = 0</td>
<td>n = 0/n = 0</td>
</tr>
</tbody>
</table>

\(^a\) Pedicle violation superior to 2 mm.

Cadaver study, Rampersaud et al. [25] determined the exposure levels following implantation of percutaneous pedicle screws under fluoroscopy control:

- the surgeon’s hands were exposed to a 58.2 mrem/min dose, which is ten to 12 times higher than during femoral nailing; wearing radioprotective gloves reduced the dose to 39.3 mrem/min;
- the thyroid received a 8.3 mrem/min dose;
- the chest received a 58.3 mrem/min dose if the surgeon was on the same side as the radiation source and only 2.2 mrem/min if on the other side.

Use of instruments 5 to 10 cm longer reduced hand irradiation by 25 to 40%.

Wild et al. calculated an X-ray exposure time of 5.7 minutes during percutaneous fixation versus 3.7 minutes during open fixation [15]. Schmidt et al. reported an X-ray exposure time of 5.99 ± 3.5 minutes for percutaneous instrumentation with two rods and four screws [16]. In a sheep study, X-ray exposure time was 1.88 ± 0.66 minutes for an open implantation versus 3.2 ± 1.4 minutes for a percutaneous implantation (P < 0.05) [14]. Overall, these data confirm the increased irradiation for the surgical team and the patient during percutaneous fixation. This is a problem for the surgeon, who will be exposed to excessive radiation over the span of his career and requires steps to be taken to reduce this exposure. Such steps include alterations to the surgical technique and the use of surgical navigation systems.

### Navigation systems and percutaneous surgery

Navigation systems aim to reduce exposure to X-rays while also improving screw placement. In a cadaver study, Foley et al. achieved 94.7% good screw positioning with no radiation to the surgeon’s hands when using computer-assisted fluoroscopic navigation [26]. These results were confirmed in clinical practice [27].

Use of 3D fluoroscopy improves the quality of screw placement relative to 2D fluoroscopy [28,29]. Use of an intraoperative CT scanner or the O Arm imaging and navigation system reduces irradiation, since images are acquired with the team outside the operative suite. Conversely, the patient is exposed to more radiation when the percutaneous screw is implanted with CT-assisted navigation in comparison to when fluoroscopy is used (65 seconds of irradiation per screw) [30]. Other techniques being developed include an electromagnetic navigation system [31] and robotics-assisted navigation [32].

### Neurological decompression

Fractures that are complicated by neurological problems are in principle a contraindication to percutaneous fixation, since decompression cannot be performed. However, percutaneous fixation can be combined with a limited posterior midline approach to perform the required decompression. In this case, the percutaneous fixation is performed first, and then a midline incision is made over the compressed area to allow for limited detachment of muscles in the

### Table 3 Duration of X-ray exposure during percutaneous or open screw fixation.

<table>
<thead>
<tr>
<th>Study</th>
<th>Duration of X-ray exposure</th>
<th>Percutaneous screw fixation</th>
<th>Open screw fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rampersaud et al. [25], Cadaver study, 96 screws</td>
<td>9.3 s exposure for one screw</td>
<td>Dose received</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hands: 58.2 mrem/min</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radioprotective gloves worn</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>39.3 mrem/min</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thyroid: 8.2 mrem/min</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chest: 53.3 mrem/min</td>
<td></td>
</tr>
<tr>
<td>Lehmann et al. [14], Sheep study</td>
<td>3.2 ± 1.4 min/screw</td>
<td></td>
<td>1.88 ± 0.66 min/screw</td>
</tr>
<tr>
<td>Schmidt et al. [16]</td>
<td>5.9 ± 3.5 min/screw</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wild et al. [15]</td>
<td>5.7 min/screw</td>
<td></td>
<td>3.7 min/screw</td>
</tr>
</tbody>
</table>

Min: minute.
cranial-caudal and lateral planes. However, indications for this type of decompression are limited.

Fusion

The need for always using a bone graft during surgical treatment of spinal fractures is highly debated and no consensus exists [9,33]. For a long time, compression fractures have been treated with immobilisation without grafting. Bone union is always obtained, thus not a concern. The true problem lies in the loss of correction, mostly in the disc but also in the vertebral body, due to insufficient mechanical strength. After open fixation without a graft, Yang et al. removed the instrumentation between nine and 12 months in all his cases [33]. Over the long-term, they observed a loss of seven local kyphosis (four in the disc and three in the vertebral body), but the clinical results were not worse after an average follow-up of 40 months. In fractures where the instability is completely bone-related (Type B2 flexion-distraction fracture), the bone instability is temporary since the instability will not exist anymore once union is achieved. This type of fracture does not require a bone graft. Thus, it seems that percutaneous fixation without grafting can be used to treat minimally displaced Type A1 and A2 fractures, Type A3 (but not A3.3) fractures and Type B2 fractures. For other fracture types, a bone graft must be added through an anterior approach or by using combination techniques (discussed below).

Indications and results

A detailed discussion on the relative merits of using conservative treatment or surgical treatment (anterior or posterior approach) for various indications will not be made here, controversy abounds and no specific recommendations exist [9,34]. The goal here is to present the treatment options provided by percutaneous fixation and to review published results.

Fixation alone

Fixation alone can only be considered for fractures with temporary bone instability: Type A (pure compression) and Type B2 (flexion-distraction). In such cases, fixation immediately provides pain relief, corrects the deformation and avoids any additional displacements.

Magerl Type A fracture

Pelegri et al. reported on the results of percutaneous fixation of 13 Type A1, A2, A3 and B2 fractures with no neurological signs, and an average initial kyphosis of 16° [21]. At the longest follow-up, the kyphosis increased by 8° on average and had an average loss of 2°. One patient needed a revision for a misplaced screw, which had caused neurological problems. The functional results were very good for Type A1, A2 and A3.1 fractures since the percutaneous fixation acted as an "internal brace". In these indications, the percutaneous fixation can be replaced by vertebral cement augmentation only, using procedures that expand the vertebrae (balloon kyphoplasty, VBS™, Spine Jack™, etc.) with satisfactory results [35–37]. The benefits include obtaining immediate pain relief and fast functional recovery, maintaining the correction by supporting the anterior spine and not immobilizing any of the disc levels. There is no published information suggesting that one technique is better than another, since no studies have been done to compare percutaneous fixation with vertebral augmentation techniques.

For some surgeons, Type A3.3 fractures are an indication for fixation only. However, because the anterior spine is not reconstructed, there is a risk of losing the reduction or breaking the instrumentation, as reported with open fixation procedures. Use of the load sharing classification (LSC) to determine if anterior spine reconstruction is needed has been validated by some published studies [18,38,39]. These studies recommend a short-segment posterior fixation for a LSC under 6. If the LSC is higher, the anterior spine must also be reconstructed. This can be performed with an anterior surgical procedure or percutaneous vertebral augmentation, in combination with fixation. Instead of adding an anterior surgical procedure, the patient can be treated with a single procedure using a posterior approach. Ni et al. reported results after a 48 month follow-up of 36 Type A fractures with a LSC below 6 that were treated percutaneously with a four-screw fixation system [18]. Although the anterior wall initially lost 42% of its height, at the last follow-up, the height loss was 10%; 86% of patients had good or excellent clinical results. The initial kyphosis was 18°; the final correction was 9° with a 4° loss of correction. This loss of correction was comparable to that reported for open posterior approaches for this type of fracture [7,11]. Logroscino prefers using long-segment fixation systems (two levels above and below) for thoracolumbar junction fractures with a LSC superior than 7 to avoid any loss of correction and avoid the need for an anterior procedure [38]. Only seven Type A2.3, A3.3 and B 2.3 were treated with this technique. There were no reported complications and very satisfactory clinical results in all cases, however the angular correction was not reported. The Palmisani et al. series included 64 fractures (57 Type A) treated with percutaneous posterior short-segment fixation [20]. An average loss of correction of 4° was observed at the last follow-up, which was greater with polyaxial screws than monoaxial screws. In two cases, the instrumentation failed and required anterior fusion, while the fractures healed in all the other cases. Wild et al. made a retrospective evaluation of fixation without fusion of Type A fractures using the Dick et al. internal fixator that was implanted percutaneously in ten cases and in an open procedure in 11 cases [15]. The quality of the reduction, amount of correction lost and complication rate were identical in both groups. However, after 5 years, the functional score was statistically higher in the percutaneous group, but there was no correlation between the final deformity and the clinical results in both groups.

Magerl Type B fracture

Type B2 fractures, which are those combining anterior compression (with moderate loss of vertebral body height) and posterior distraction of the bony structures, are an excellent indication for percutaneous fixation alone. The fixation procedure closes the posterior fracture line, corrects
the posterior distraction by adding compression and restores the vertebral body height when combined with patient positioning. If the anterior correction is not sufficient, it can be improved by adding an intravertebral augmentation system (Figs. 3–7). The correction creates a dead space that is then filled with cement to avoid secondary loss of correction (Fig. 3). Once bone union occurs, the instrumentation can be removed, especially since the discs are intact in this type of fracture (Fig. 8) [40]. Beringer reported on the first two cases of change-type fractures treated with the Sextant™, the radiological and functional results were very good [41]. Other published series have included Type B fractures, but specific results were not reported for this type of fracture [21,38].

Type B1 fractures with ligament involvement, which are rarer, are not an indication for percutaneous fixation alone in our opinion, since a bone graft must be added to obtain fusion and make up for the ligament injuries. Minimally invasive procedures for the fusion have a place here in combination with percutaneous fixation.

Percutaneous fixation in combination with other techniques

Three techniques can be combined with percutaneous fixation: open anterior surgical approach, minimally-invasive posterior techniques and percutaneous vertebral reconstruction techniques.
three patients had a lung infection without any infection in the posterior fixation system. There were two revisions: one for a paravertebral haematoma and one for fixation system failure after 6 months. Three patients needed a blood transfusion after an additional anterior procedure.

Combination of percutaneous fixation with minimally-invasive surgery

This applies to cases where percutaneous fixation is mechanically sufficient but the fracture requires an intersomatic graft to avoid angular loss of the disc space [40]. Minimally-invasive spine surgery techniques are used to perform this grafting step.

Maciejczak et al. described a technique consisting of combining percutaneous fixation with a minimally-invasive approach (keyhole access) for the intersomatic grafting step [43]. Clinical results were good despite 3° to 8° loss of correction. Maciejczak et al. stated that this technique was harder than an open technique and required the surgeon to be experienced in minimally-invasive surgery and ready for an extended operative time (between 4.5 and 7 hours for the procedure). They only use this technique for Magel Type A3 or B fractures without neurological problems, but with a significant comminution of the superior end plate. The drawback of this technique is the requirement to perform an arthroscopy and bilateral pediculectomy, which worsens the instability of the fracture and could be the cause of the reported loss of correction. Intersomatic fusion through a unilateral transfenoral route using a minimally-invasive approach can be combined with contralateral percutaneous fixation using the same technique as the one used for degenerative diseases.

Combination of percutaneous fixation with percutaneous anterior spinal reconstruction techniques

This combination applies to fractures not needing a graft, but where fixation alone is not mechanically sufficient (LSC > 6) and requires anterior spinal reconstruction. Another benefit is that the subsidence of the superior end-plate is reduced, which avoids secondary intervertebral loss of correction [40]. Fractures meeting these criteria included Type B2 bone fractures and Type A3.3 fractures, which have significant vertebral compression leading to loss of vertebral body height and an anterior bone void. In a cadaver study, Mermelstein et al. showed that adding cement in the vertebral body along with a posterior short-segment fixation reduces the flexion moment on the pedicular screws by 59% in flexion and 38% in extension, which increased the fixation system stiffness by 40% relative to a posterior fixation system alone [44]. Anterior spinal reconstruction using intravertebral expansion systems were initially described for use with Type A3.1 and A3.3 fractures, where a posterior short-segment fixation system was used in combination with an open balloon kyphoplasty procedure [19]. This technique provided a 66% to 80% correction of the central subsidence, 71% to 91% correction of the anterior subsidence and the kyphosis was corrected from 11° to -1.6°. However, Verlaan et al. observed a loss of intraoperative correction after the balloon was released, but before cement was injected into the vertebral. There were six instances of leakage in 21 cases, one of which went into the spinal canal, but

Figure 8  Sagittal MRI slices, T2 sequence at 1 year after surgery, before the instrumentation was removed; no disc disease can be found in the levels above and below the fracture site.

Combination of percutaneous fixation with open surgery

Percutaneous fixation is a temporary solution in these cases; the bone grafting and anterior spine reconstruction will be done during a subsequent open procedure. In a polytrauma patient, a spinal fracture complicates the treatment. These fractures are sometimes operated on secondarily, especially if the patient had resuscitation complications, which leads to problems due to non-anatomical reduction of the spinal deformity and makes the second surgery much more complex. Because percutaneous fixation is fast and not very invasive, it has an important role here – the spine can be stabilized in an emergency setting while limiting the risks of making the patient’s condition worse. Thus the fracture is stabilized in the emergency ward, which restores the spinal shape and allows the patient to be moved (skin care, semi-upright seated position for ventilation, etc.) and transported (for imaging studies) without having to worry about the fracture displacing and causing neurological problems. Once the patient leaves the acute intensive care phase, an additional fixation and fusion procedure will be performed through a minimally invasive anterior approach. All fractures can be treated this way when there are no neurological problems, especially Type A3.3, Type B1 fractures and even Type C fractures, if the posterior structures are not dislocated or greatly laterally displaced, which would require an open posterior reduction. If there is chest trauma, early fixation of a spinal fracture allows the patient to be mobilized and participate in rehabilitation while limiting respiratory complications [16,42]. The technique follows the principles of spine damage control established for polytrauma patients. Schmidt et al. reported on his experience with percutaneous long-condition thoracic fixation done in the emergency ward on 27 patients with an ISS superior to 16, with 20 of them also having chest trauma [16]. Only two patients developed acute respiratory distress syndrome and

Percutaneous fixation of thoracolumbar fractures: Current concepts

907
without sequela [19]. Marco and Kushwaha treated 38 patients with posterior short-segment fixation during an open procedure in combination with balloon kyphoplasty for Type A and B fractures, or Type C fractures with an LSC below 7 [45]. A 14° kyphosis correction was achieved; the loss of vertebral body height went from 42% to 14% of normal, with no loss of correction after 2 years of follow-up. There were two cases of screw breakage but no cases of cement leakage. Afzal reported the similar results in terms of angular measurements on X-rays (kyphosis went from 9.4° to −1.8°) and subsidence (anterior subsidence went from 71% to 90% of normal) for 14 Type B and four Type C fractures [46]. The posterior wall did not collapse more in any of the cases. Thus, an open balloon kyphoplasty procedure in combination with posterior short-segment fixation helps not only to correct angular and vertebral body height losses, but to maintain this correction over time. The hospital stay was four days versus eight days for the open procedure [45]. Korovessis et al. [22] treated 18 Type A3 or A2 fractures by combining percutaneous fixation with balloon kyphoplasty. The local kyphosis was corrected by 14° and the anterior wall height loss went from 57% to 87% after the surgery. The VAS score went from 7.5/10 before the surgery to 3.1/10 at discharge, which occurred on the second postoperative day. The surgical time was 45 minutes and there were four cases of cement leakage into the intervertebral space [22].

These small patient series demonstrate that percutaneous fixation in combination with balloon kyphoplasty provides satisfactory, long-lasting fracture reduction with shorter rehabilitation time and hospital stays. This is in addition to not having any blood loss and to having excellent clinical results. But prospective and preferably randomized studies with a larger number of patients are needed to confirm these results.

Conversely, use of these combined percutaneous reconstruction techniques again increases the irradiation of the patient and surgical team, thus must be factored into the indications.

**Instrumentation removal**

Removal of the fixation system aims to free up the immobilized lumbar levels. Although no consensus exists, it seems logical to remove the instrumentation 8 to 12 months after the fracture has been immobilized. Wild removed the instrumentation in all his patients and found a loss of intervertebral space correction during the year after the removal, although this loss did stabilise over time [15]. Implant removal can be easily performed using the cutaneous scar at each screw level, allowing screw and rod removal without extended approach.

**Conclusion**

The role of percutaneous spinal fixation and posterior minimally-invasive surgery is becoming clearer. They do not replace the other open techniques, but add to treatment options. The advantage of these techniques in reducing surgical morbidity, simplifying the immediate postoperative recovery and improving the medium-term functional results is well known. Prospective randomized studies with a larger number of patients will be essential in better defining the indications for these various techniques. Percutaneous fixation is not always performed alone; it can be combined with additional anterior or minimally-invasive posterior routes. On-going developments in posterior minimally-invasive spine surgery will, without a doubt, widen the scope of its indications.

**Disclosure of interest**

The authors declare that they have no conflicts of interest concerning this article.

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Percutaneous fixation of thoracolumbar fractures: Current concepts


