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Percutaneous fixation of thoracolumbar vertebral fractures

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- Surgical treatment of patients with thoracolumbar vertebral fracture without neurological deficit is still controversial.
- Management of vertebral fracture with percutaneous fixation was first reported in 2004.
- Advantages of percutaneous fixation are: less tissue dissection; decreased post-operative pain; decreased bleeding and operative time (depending on the steep learning curve); better screw positioning with fluoroscopy compared with an open freehand technique; and a decreased infection rate.
- The limitations of percutaneous fixation of vertebral fractures include increased radiation exposure to the patient and the surgeon, together with the steep learning curve for this technique.
- Adding a screw at the level of the fractured vertebra has the advantages of incorporating fewer motion segments with less operative time and bleeding. This also increases the axial, sagittal and torsional stiffness of the construct.
- Percutaneous fixation alone without grafting is sufficient for treating type A and B1 (AO classification) thoracolumbar fractures with satisfactory results concerning kyphosis reduction when compared with open instrumentation and fusion and with open fixation.
- Type C and B2 fractures (ligamentous injuries) should undergo fusion since the ligamentous healing is mechanically weak, increasing the risk of instability.
- This review offers a detailed description of percutaneous screw insertion and discusses the advantages and disadvantages.

Keywords: fracture stability; thoracolumbar fractures; percutaneous fixation

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Introduction

Thoracolumbar (TL) fractures are the second most common fractures after hip fractures.[1,2] At the TL junction (T11-L2), TL fractures comprise three-quarters of total spinal injuries.[3] Most TL fractures occur at a young age, motor vehicle accidents being the most common cause. The incidence of these fractures is increased in the elderly and their occurrence is one of the markers of osteoporosis.[4,5] The main goals of treating TL fractures are: (1) to protect neural elements and maintain/restore neurologic function; (2) to prevent or correct segmental collapse and deformity; (3) to prevent spinal instability and pain; (4) to permit early ambulation and return to function; and (5) to restore normal spinal mechanics.[6] It is unanimously agreed that vertebral fractures associated with neurologic deficit should undergo surgical decompression, fixation and fusion;[7,8] however, surgical treatment of patients with vertebral fractures without neurological deficit is still controversial.[9] Unstable (> 50% loss of anterior vertebral height, > 20° angular deformity and contiguous fractures) thoracic compression and burst fractures could collapse into further kyphosis.[6,10] There is some evidence that patients who accepted surgery in these cases have shown better clinical and radiological outcomes than patients managed non-operatively,[11] with improved local kyphosis at long-term follow-up.[12]

Classically, surgical treatment consisted of internal fixation and arthrodesis using open approaches.[6] Percutaneous pedicle targeting was first described by Dick et al in

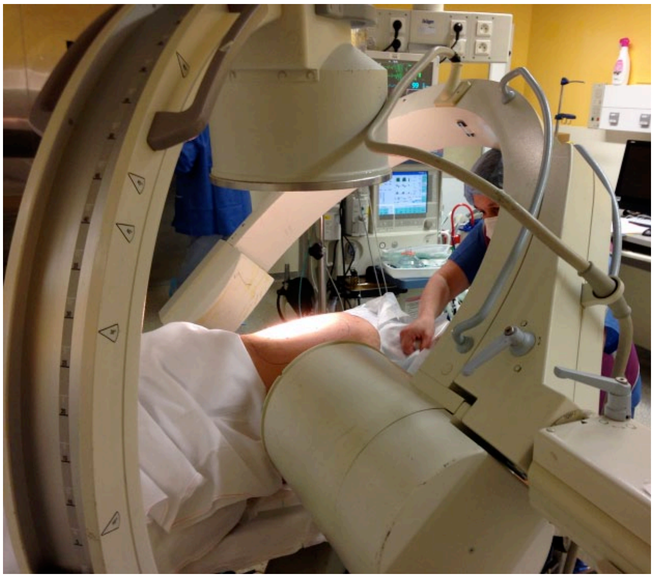

Fig. 1 Positioning of the patient with two fluoroscopy machines for anteroposterior and lateral imaging. (Adapted from Sebaaly et al[5]).

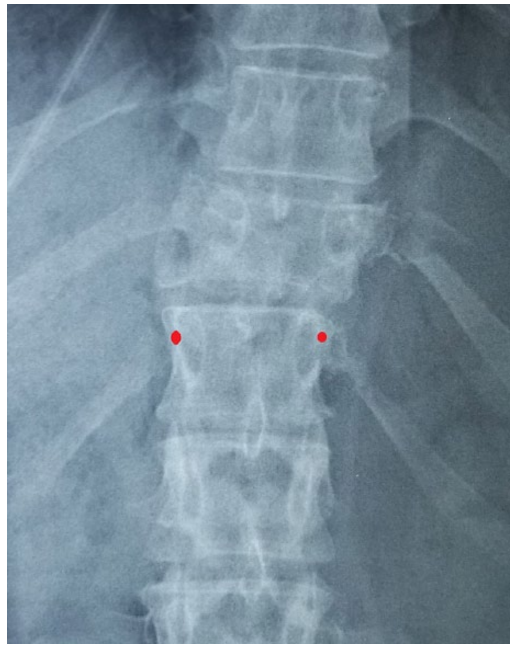

Fig. 2 AP fluoroscopy showing the desired pedicular entry points at 2–3 o'clock in the right pedicle and 9–10 o'clock in the left pedicle.

1985 for diagnosis of degenerative disc disease.[13] Foley et al reported, in 2001, the first case of degenerative disease managed by percutaneous fixation,[14] while Assaker first reported, in 2004, the management of vertebral fracture with percutaneous fixation.[15] Since then, many publications were issued describing the advantages and disadvantages of this technique.

The aim of this paper is to review the available literature and to meet the following objectives: (1) describe the pedicle targeting technique, (2) determine the advantages and limitations of percutaneous fixation of TL fractures; and (3) determine the controversies surrounding this method.

Pedicle screw insertion technique

Pedicle screw insertion could be carried out under general, local or spinal (epidural) anaesthesia. We favour general anaesthesia as it is associated with less patient discomfort. Minimally invasive or percutaneous pedicle screw placement was made easier with the advent of cannulated screws. The surgical procedure may be fluoroscopy-assisted or, recently, navigation-assisted.

Fluoroscopy-assisted technique

Fluoroscopy is one of the limiting factors of this technique as it is imperative to obtain true anteroposterior (AP) and lateral views of the desired vertebra.

The patient is positioned on a radiolucent table (or a Jackson frame) and accurate AP and lateral true views are obtained. We prefer the use of two fluoroscopy machines (Fig. 1) as this renders this technique easier even for inexperienced users, since AP and lateral views can be obtained simultaneously.[16] When the pedicle of the desired vertebra is localized, the skin entry point is marked 1 cm lateral to the pedicle. As a more convergent and straightforward pedicle screw trajectory is preferred, the entry point should be at 2–3 o'clock in the right pedicle and 9–10 o'clock in the left pedicle (Fig. 2).

Local anaesthesia is applied from the skin to the pedicle in order to decrease post-operative pain. A skin incision is made and depends greatly on the instrumentation type: older instrumentations require bigger skin incisions. The incision of the TL fascia should be wider than the skin incision. The Jamshidi needle is then introduced through the desired entry point: this is ideally localized at the junction between the articular facet and the transverse process (Fig. 3a). This will ensure a truly convergent screw placement. Care should be taken not to insert the screw through the facet joint. The Jamshidi needle is then advanced into the pedicle with simultaneous control on the AP and lateral views: when the Jamshidi needle is in the middle of the pedicle on the AP view, it should have passed the middle of the pedicle on the lateral view, and when the tip of the needle arrives at the posterior border of the vertebral body on the lateral radiograph, it should not be touching the inner border of the pedicle on the AP view. This is in contrast to the technique for vertebral augmentation, as a safety zone of 3 mm medially should be left in this case. The tip of the needle is only allowed to

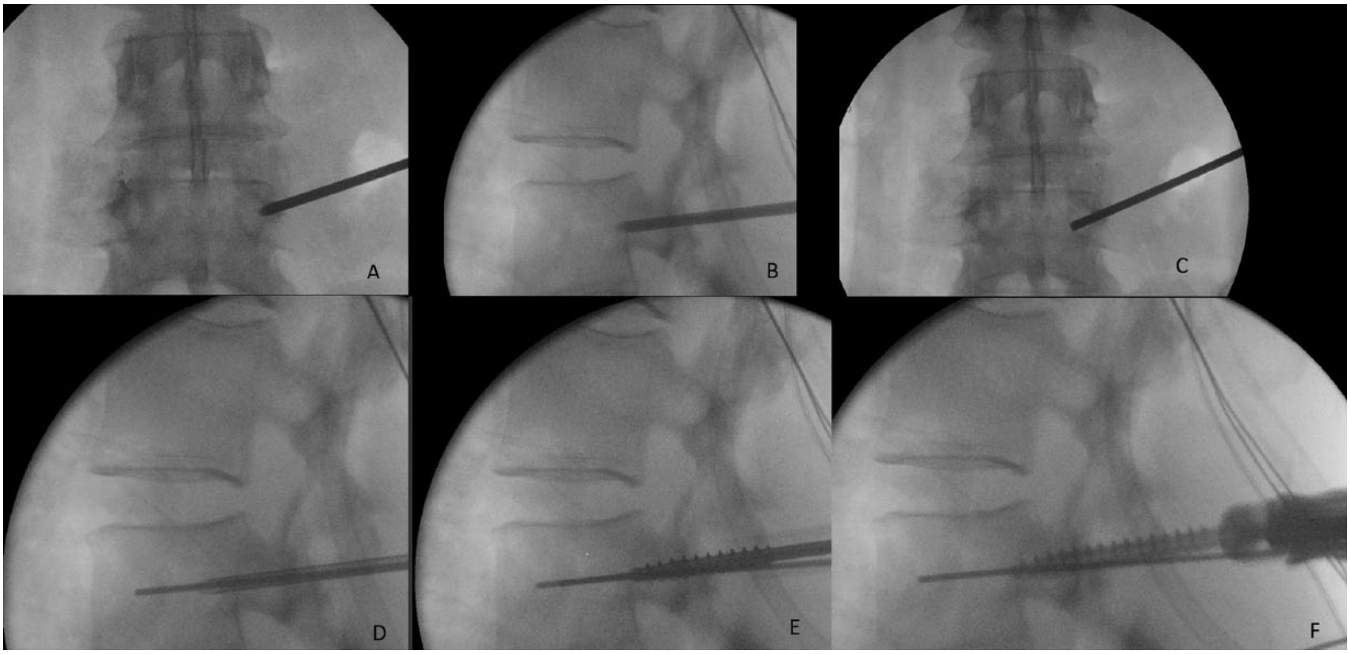

Fig. 3 Described technique for screw insertion using fluoroscopy. (A) Entry point on the AP fluoroscopy; (B, C) When only the Jamshidi needle passes the posterior wall of the vertebral body, it is allowed to touch the inner border of the pedicle on the AP image; (D) The guide wire is then inserted in the cannula with care not to pass the anterior wall of the vertebral body; (E) After the insertion of all guidewires, taping is carried out with caution not to remove the guidewires; (F) Screw insertion is carried out and the guidewire may be removed when the screw tip reaches the posterior vertebral wall.

touch the inner pedicle wall on the AP radiograph when it has passed the posterior wall (Fig. 3b and c). The needle should always be parallel to the vertebral endplates on lateral film when advancing into the vertebra.

The guide wire is advanced into the vertebral body with care not to pass the anterior cortex (risk of injury of the greater vessels) (Fig. 3d). The trickiest step is to remove the Jamshidi needle without removing the guide wire. Prono-supination is used to retract the needle while the guide wire is maintained with a Kocher clamp. When guide wires are inserted in all desired vertebrae, the AP fluoroscopy machine can be drawn out of the operative field to ensure a more ergonomic work space.

Pedicle preparation then begins, using cannulated instruments such as awls and taps while the instruments' depth is frequently checked on lateral imaging (Fig. 3e). The screws are then inserted and the guide wire removed after the tip of the pedicle screw passes the posterior border of the vertebral body on the lateral radiograph. One pitfall to avoid is the bending of the guide wire while tapping and inserting the screw as this might result in guide wire breakage. To avoid this complication, the guide wire should be removed as soon as the screw tip enters the vertebral body at the posterior vertebral wall (Fig. 3e).

After insertion of all desired screws, contouring of the rods is performed and these are inserted and locked in place. Final AP and lateral imaging should be obtained to control the construct.

In the immediate post-operative period, no bracing is required. Pain is managed for a limited period of time with acetaminophen and narcotic medication. Most patients can be released on the second post-operative day if pain is acceptable, neurologic examination is normal and all other associated injuries are addressed.

Navigation-assisted technique

With the advent of navigation, there is increasing use of this technology in spine centres as it renders safer and faster insertion of pedicle screws.[17] The technique described here uses the O-ARM (Medtronic, Sofamor, Memphis, TN, USA) as an image acquisition system and Stealthstation TREON™ system (Medtronic Sofamor Danek, Memphis, TN, USA) as a navigation system. After positioning, the first step of this technique is inserting the reference. We prefer a percutaneous iliac bolt reference guide (Fig. 4a). Care should be taken that the reference guide does not block the navigation field. O-ARM image acquisition is then carried out. We prefer the use of two images on the navigation panel: axial and sagittal cuts (Fig. 4b).

The skin incision is marked in a similar fashion to the fluoroscopy-assisted technique. The insertion of the navigated Jamshidi needle follows the same principles of the

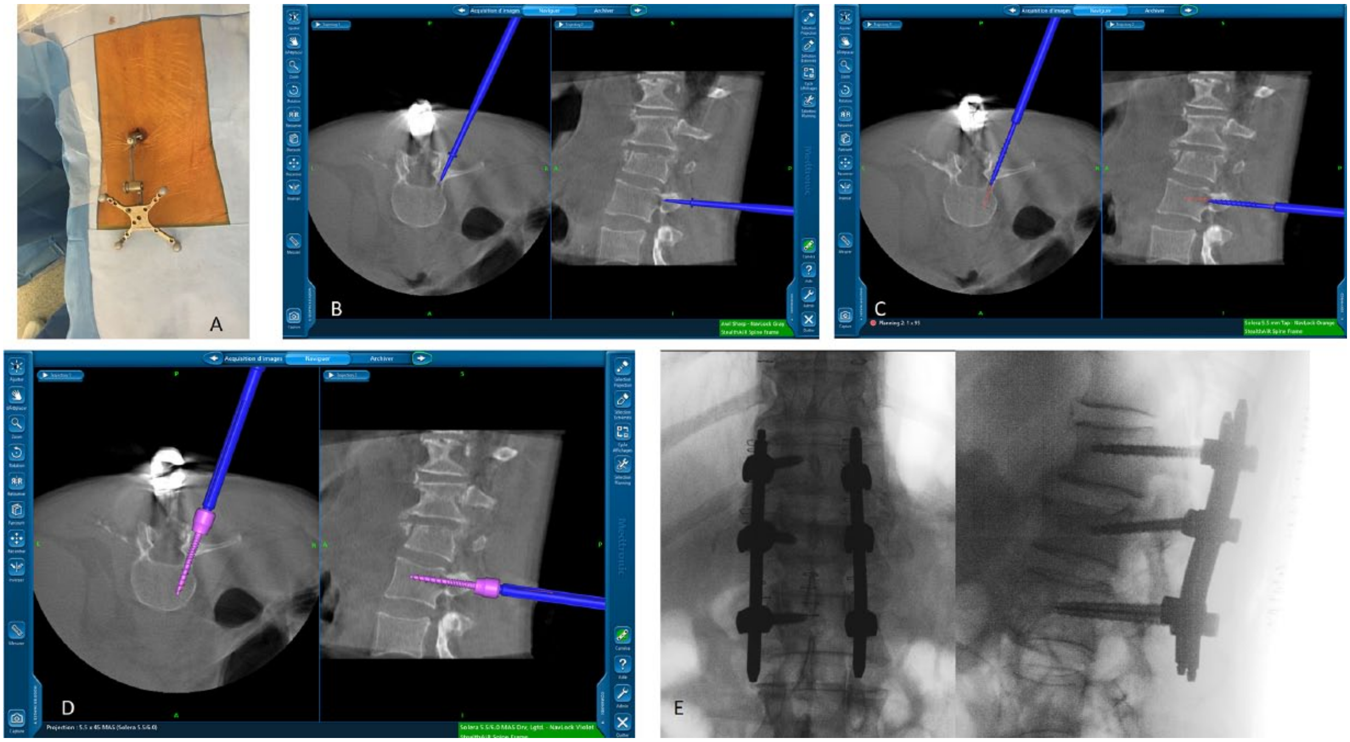

Fig. 4 Described technique for screw insertion using O-ARM. (A) We favor the use of the percutaneous navigation bolt; (B) The navigated pedicle finder is advanced with regular checks on the axial and sagittal views; (C) Navigated taping is carried out; (D) Screw insertion is carried out; (E) Final result.

technique described above. The use of guide wires in this technique is optional. If a guide is used, we perform an AP and lateral imaging (equivalent to fluoroscopy) using the O-ARM just to check the correct position of the guide wires as some cortical breaches may occur during the learning curve of this navigation-assisted percutaneous instrumentation technique (Fig. 5). To ensure rapid insertion of the screws, we tape all the screws using the navigated tap (Fig. 4c). Screw insertion is made easier with the navigation model (Fig. 4d) and rod insertion is performed similarly to the fluoroscopy-assisted technique described above (Fig. 4e).

Percutaneous internal fixation for traumatic fractures

Advantages of percutaneous fixation

The most important theoretical advantage of percutaneous fixation of vertebral fractures is less tissue dissection. Regev et al showed that the multifidus muscle motor nerve was injured in up to 80% of patients in open procedures compared with only 20% in patients operated on with the percutaneous technique.[18] The preservation of muscle innervation would result in less muscle scarring and atrophy as shown on post-operative muscle enzyme dosage[19] and MRI.[20] This same study showed better muscle strength preservation in the percutaneous group.[20]

This less traumatic approach to spinal muscle should theoretically result in decreasing post-operative pain. Jiang et al found better function and lower pain scores in the percutaneous group compared with the open cohort,[21] the same result as shown in other papers.[2] On the other hand, Lee et al found no difference in VAS scores between the percutaneous group and the open fixation group.[22] Similarly, a recent meta-analysis showed no difference in medium-term follow-up pain between both techniques.[23] This could be explained by the higher heterogenicity between the different studies.[24] Even though no differences in pain scores at long-term follow-up were observed, percutaneous fixation resulted in lower VAS scores at early follow-ups (three months), resulting in early mobilization (caused by better spinal stability).[22,25-27]

This allows patients to ambulate earlier and thus to be less exposed to bed rest complications and ulcers.[20,22] This will result in a significant decrease of patients' hospital stay (mean decrease of 5.72 days),[24] thus decreasing the hospitalization cost, including the cost of the osteosynthesis material, with an average gain of €1159.11 per patient.[21,28]

Another possible advantage of percutaneous fixation is decreased bleeding and operative time. Many authors showed lower blood loss in percutaneous fixation when

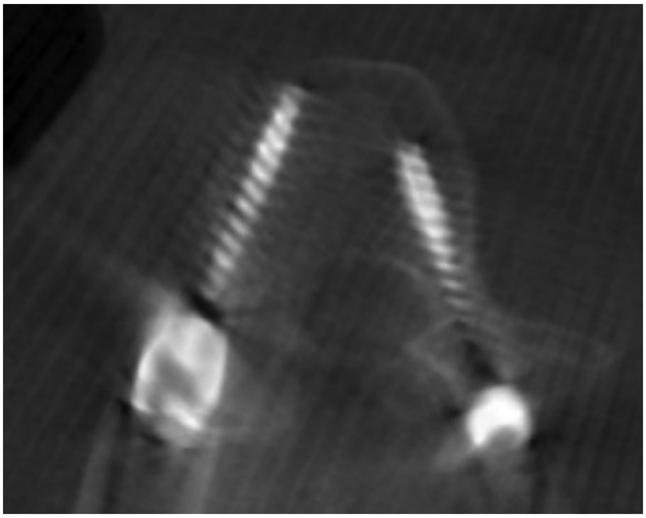

Fig. 5 Postoperative CT scanner showing extrapedicular 'safe' trajectory of the right pedicle screw.

compared with standard open fixation in their series. Merom et al found 50 mL less blood loss using the percutaneous technique. Nonetheless, this result was not statistically significant.[29] Yet others found a significantly decreased blood loss with the minimally invasive technique.[21,22,26,27] When these results are pooled into a meta-analysis, percutaneous fixation resulted in significant surgical bleeding reduction of 285.44 mL with a relative reduction of 1.67.[23,24]

Operative time depends greatly on the experience of the operating surgeons. As a matter of fact, early reports showed no difference between the two techniques.[29] More recent publications, in which operating surgeons have completed their learning curve, showed decreased operative time compared with open techniques.[21,22,26,30] When data from randomized trials are pooled together, percutaneous fixation resulted in a significant reduction of operative time by a mean of 18.83 minutes.[23,24]

Fluoroscopy-controlled pedicle screw placement is associated with better screw positioning compared with a freehand technique. Ringel found only 3% of unacceptable screw placements using the percutaneous technique, while Ni et al found 6.7% screw misplacements overall but without neurological involvement.[31] Nonetheless, one meta-analysis showed that there was no difference in terms of screw malpositioning between percutaneous (3.0%) *versus* open fixation (4.2%).[24] One should note that the open freehand technique tends to malposition the screw medially, whereas the malpositioned screw under fluoroscopy tended to be in the 'safer' lateral zone (Fig. 5).[32]

Finally, the infection rate with percutaneous fixation seems to be decreased compared with open fixation. Schmidt et al had no infection in their series of 74 patients operated on with percutaneous fixation,[33] whereas Ni et al showed one infection in 36 patients (2.7%).[31] These rates of infection are somewhat below the known infection rate in trauma cases when open fixation is performed. In fact, the meta-analysis by Phan et al showed that infection rates were significantly lower in the percutaneous fixation cohort compared with the open fixation cohort (0.3% *vs* 3.4%, respectively; relative risk (RR) = 0.36).[24]

Drawbacks of percutaneous fixation

Percutaneous instrumentation of a fractured vertebra requires the use of fluoroscopy, thus increasing the exposure to the patient and the surgeon. Rampersaud et al studied the exposure in a cadaveric study, showing that surgeons' hands were 10 to 12 times more exposed to radiation in a short segment fixation compared with a standard femoral nailing. They also showed that the surgeon's chest received 25 times more radiation if the surgeon was on the same side as the radiation source compared with when he was on the other side.[34] The newer technology with intra-operative cone-beam CT intends to address this drawback while increasing pedicle screw position accuracy. In a matter of fact, correct pedicle screw placement increased significantly using this technology.[32,35,36] Surgeon and surgical team exposure to radiation was significantly reduced, but the patient was more exposed to radiation with this technology.[37] The patient's radiation exposure could be decreased using 'low dosage' or 'paediatric dosage' protocols.[38] Still, this technology requires financial investment in the operating room (reinforced floor, lead protected room, etc.) as well as in the acquisition system along with the navigator and ancillary.[39]

Another possible drawback of percutaneous fixation of TL fractures seems to be the learning curve. Many authors commented on the challenges faced in their initial cases, with increased incidence of complications caused by facet joint violations, screw misplacement and subsequent need for additional operative procedures.[40-42] In 2014, Sclafani et al published a systematic review correlating complications to the technique learning curve.[43] They found that screw malposition and loosening depend largely on the surgeon's experience. They stated that 20 to 30 cases are required to complete the learning curve for this technique. Experts stress the importance of completing this learning curve to decrease overall complications, including mechanical and infectious ones.[44] Nonetheless, when compared with other minimally invasive (MIS) techniques (MIS decompression, MIS anterior interbody fusion, etc.), percutaneous screw fixation is associated with the shortest and easiest learning curve.[43]

Controversies

Surgical management of neurologically intact vertebral fractures is still controversial and analysing the indications of surgical treatment is beyond the scope of this review.

Nonetheless, two points should be emphasized. First, the local and regional kyphotic deformities are among the least studied parameters in non-operative treatment. In fact, the TLICS scoring system was criticized for not incorporating the local kyphosis in the treatment algorithm.[10] Moreover, the latest meta-analysis by Sonali et al showed no difference between non-operative and operative treatments in pain and clinical outcomes but showed better kyphosis correction with operative treatment.[12] However, one question remains: is fusion necessary for long-term kyphosis prevention? Lyu et al compared open instrumentation and fusion with open fixation and percutaneous fixation.[25] They found no difference in kyphosis reduction with the three techniques and concluded that percutaneous fixation alone without grafting is sufficient for treating these fractures. The same conclusion was also reached by other authors.[26,45] Meta-analysis data showed no difference of kyphosis correction at the immediate postoperative period or at the last follow-up between these three techniques.[23,24] The fixation would act as an internal brace and could be removed afterwards. Kim et al evaluated motion at the fractured level after removal of the implants in percutaneous fixation of burst fractures, and showed motion preservation at the fractured level with good clinical results.[46] Finally, there may be a risk of facet violation and a subsequent risk of facet osteoarthritis (OA) even after instrumentation removal. Tromme et al evaluated more than 1000 screws inserted percutaneously for fractures with several interesting findings.[47] The facets were moderately breached in 15% of cases and severely damaged in only 0.6% of cases. Moderate OA was found in 9.6% of cases, while 1.2% of cases showed severe OA. Complete fusion was found in 1%, whereas partial fusion was evidenced in 2.6% of cases. The main risk factors for facet violation and fusion were age, increased BMI and type B fractures.[47]

Anterior support for posterior fixation is another controversy, and decision for anterior support is still based on the load sharing classification (LSC) described by McCormack et al in 1994.[48] Many authors encourage the use of anterior support when the LSC score is > 6.[49] Anterior support could be made by minimally invasive approach (mini-open, thoracoscopy) for corpectomy and cage insertion.[49] However, these anterior approaches are less familiar to spine surgeons, with higher complications (up to 7.8% vascular injuries), and they often require access surgeons.[50] In addition, these recommendations are based on an old classification, while newer and more powerful instrumentations are now available for the operating surgeon. For instance, Kanna et al showed no loss of reduction nor increasing kyphosis in a series of 32 patients with LSC ≥ 7 operated with short segment posterior fixation (including the fractured vertebra) with no implant failure.[51]

Classically, treatment of TL fractures consisted of a long construct with three levels of fusion above and two levels of fusion below the fracture, together with the three-point bending fixation to prevent kyphotic deformity.[6] The classical long construct is somehow technically difficult because of the multiple positions needed for the fluoroscopic machine together with the inability to use transverse connectors necessary for this long construct. In 1994, Dick et al described a technique adding a screw to the fractured vertebra with the advantages of incorporating fewer motion segments into the fusion mass, with less operative time and bleeding. This also increased the axial, sagittal and torsional stiffness of the construct.[52] The use of this technique obviates the need for a long construct (Fig. 6). Some authors described even shorter constructs to decrease fusion levels. Wei et al described mono-segmental fixation. They showed better operative time and average blood loss but kyphosis reduction loss for LSC ≥ 7.[53] Others found that only increased BMI (> 30) is a risk factor for kyphosis in short segment fixation including the fractured vertebra.[54] Adding screws at the fractured level decreased the mechanical complications related to instrumentation failure[2] and increased construct stiffness by 31% with better support of the fractured vertebral body during flexion-extension loading.[55] A biomechanical study evaluated the strain on the instrumentation in short segment instrumentation. They showed maximal strain in four screw constructs (including monosegmental); however, adding at least one screw at the fractured level significantly decreased the strain on screws and rods.[56] Finally, a recent study showed no increase of blood loss or operative time when screws are added at the fractured level.[2]

One could argue that most studies compared percutaneous fixation with open reduction and fusion in patients with type A (according to AO classification[57]) fractures where the fracture is inherently stable. Type B fractures, especially B2, where ligamentous instability is present, leads to a weak scar compared with bony B1 fractures and could lead to long-term instability and neurological compromise. Nonetheless, the conclusions drawn on type A fractures could be extended to neurologically-intact type B fractures. In fact, Grossbach et al compared open fixation with percutaneous fixation in distraction type B fractures.[30] They found no difference in kyphosis reduction loss in both groups at final follow-up, with more patients in the percutaneous fixation group undergoing implant removal.[30] These same results were found by Dong et al, who evaluated regional kyphotic angle as well as vertebral height.[27]

Finally, spinal canal compromised by a bony fragment without neurological compromise remains a relative indication of open fixation and decompression. Yet, some authors showed reduction of the canal compromised from 43% to 23% in well reduced fractures treated percutaneously.[58] These results are comparable with those obtained when open reduction and fusion are performed.[59]

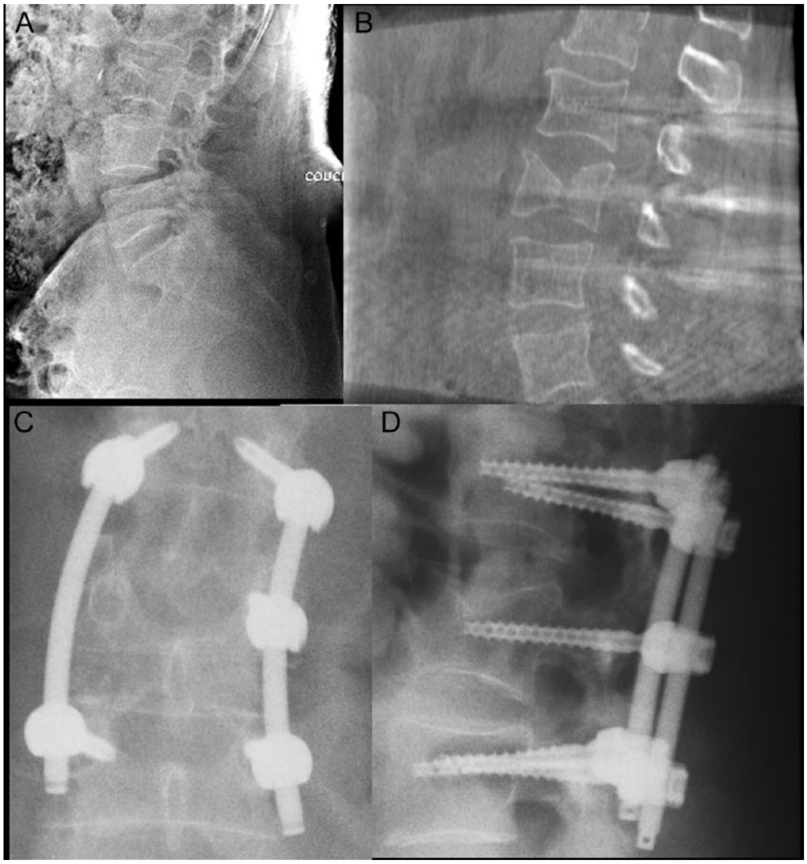

Fig. 6 A 55-year-old woman was the victim of a fall from the second floor. Initial X-ray and CT scanner showed A2 L3 fracture (A-B). She was operated with percutaneous fixation with instrumentation of the fractured vertebra in its left pedicle (C-D).

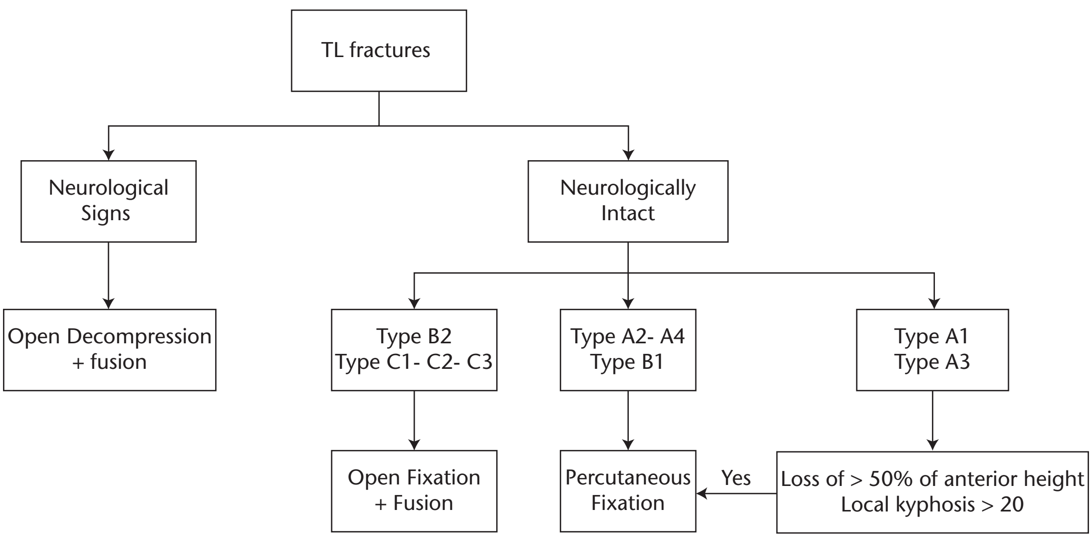

Fig. 7 Algorithm for treating thoracolumbar vertebral fractures.

Authors' recommendations

Based on this review, we propose a treatment algorithm for TL fractures (Fig. 7). Patients who present with neurological signs should undergo posterior (and/or anterior) decompression and fusion. Detailed evaluation of the fracture of neurologically intact patients is mandatory. Type C and B2 fractures (ligamentous injuries) should undergo fusion since the ligamentous healing is mechanically weak, therefore increasing the risk of instability. Type B1 and A4 fractures, as well as type A2 fractures, could undergo percutaneous short segment fixation with screws at the fractured level. A1 and A3 fractures with a loss of 50% of anterior height or 20° of local kyphosis could undergo the same treatment. Whenever possible, the fractured vertebra should be instrumented with a minimum of one screw.

Conclusion

Percutaneous fixation in type A and B1 fractures meets the main goals of treating TL vertebral fractures, by protecting neural elements, preventing collapse, deformity, instability and pain and allowing early mobilization and return to function. This technique, while having a steep learning curve with increased surgeon and patient exposure to radiation, minimizes tissue dissection, operative time after adequate training, post-operative pain and infection rate when compared with open reduction, fixation and fusion. More stability is acquired by adding screws at the level of the fractured vertebra. This allows for shorter constructs, shorter operative time, less blood loss and increased mobility. However, for more unstable fractures (type B2 and C fractures), fusion with a complementary anterior intervention or with an open posterior approach is necessary to compensate for the weak ligamentous healing.

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