Scoliosis surgery in adulthood: what challenges for what outcome?

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Abstract: Adolescent idiopathic scoliosis that has progressed over time, *de novo* scoliosis, and degenerative scoliosis represent different types of adult spinal deformity (ASD). Functional impairment and muscular fatigue are due to sagittal and coronal imbalance of the trunk. Surgical treatment can provide a significant improvement of three-dimensional (3D) thoracolumbar alignment, function, and health-related quality of life (QoL). A patient-specific benefit-risk assessment, including clinical expectations, comorbidities, and the spinal deformity itself, has to be done preoperatively since the risk for mechanical complications is relatively high. Minimal invasive techniques combine posterior percutaneous instrumentation and lateral interbody fusion cages which enables vertebral realignment and indirect foraminal stenosis decompression. This strategy seems appropriate in mild and moderate ASD with a limited number of degenerated segments in the lumbar spine and remaining curve flexibility. Severe ASD needs to be addressed by open surgery, which combines posterior instrumentation, interbody fusion, and osteotomies in stiff deformities. Longer posterior instrumentation of the thoracolumbar spine, the sacrum, and the pelvis carries a risk for mechanical complications such as non-union and proximal junctional kyphosis (PJK). Modern surgical techniques including circumferential lumbosacral fusion and double rods might lower the risk for non-union. Accurate sagittal alignment planning, setting the lumbar sagittal apex according to pelvic incidence, and segmental lordosis distribution, are mandatory for minimizing the risk of PJK.

Keywords: Adult scoliosis; spinal deformity; sagittal malalignment; spinal stenosis; surgery; spinal instrumentation; complications

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Introduction

Adolescent idiopathic scoliosis that has progressed over time, *de novo* scoliosis, and lumbar degenerative scoliosis are the most common types of three-dimensional (3D) deformities among adult spinal deformity (ASD). In the aging population, intervertebral disc degeneration, facet joint osteoarthritis, paravertebral muscle dystrophy with fat infiltration, postmenopausal ligament laxity, and osteopenia all represent factors that might lead to an ASD. Adult scoliosis is usually associated with the loss of lumbar lordosis and a kyphotic deformity at the thoracolumbar junction (*Figure 1*). This leads to anterior imbalance of the trunk, which is compensated by retroversion of the pelvis and flexion of the knees. Sagittal malalignment in adult scoliosis has an impact on health-related quality of life (QoL) since

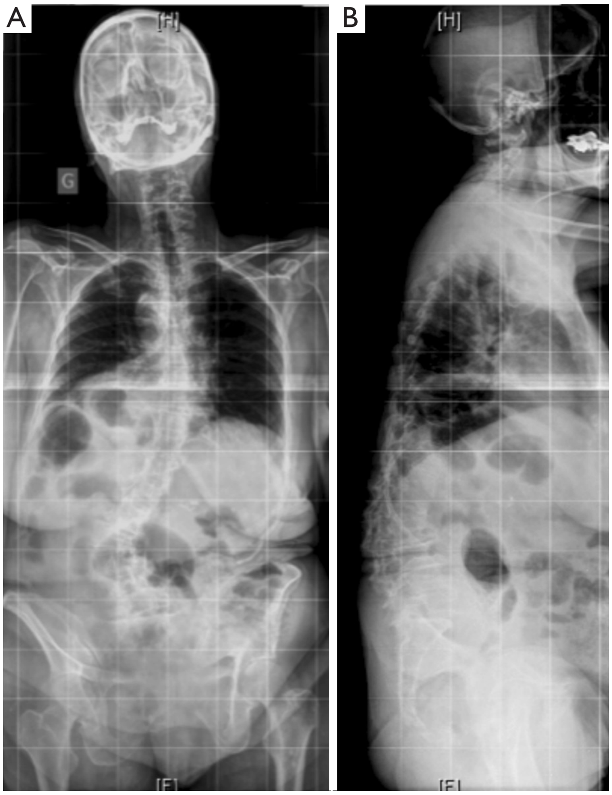

Figure 1 (A) Postero-anterior full spine radiograph showing a degenerative scoliosis and a pelvic tilt in the coronal plane, (B) the lateral full spine radiograph demonstrates a loss of lumbar lordosis and a kyphosis at the thoracolumbar junction (sagittal malalignment), which is compensated by retroversion of the pelvis and thoracic lordosis.

the energy expenditure of paravertebral muscles increases to counteract anterior imbalance, leading to back pain, fatigue and functional impairment (1,2).

Degenerative changes of the lumbar spine may also lead to canal and foraminal stenosis in adults with scoliosis. More than 90% of patients that present radicular pain have a foraminal or lateral recess stenosis on magnetic resonance imaging (MRI) or computed tomography (CT), and it is usually located at level with intervertebral rotation and dislocation (3). Different patterns of stenosis due to lateral subluxation have been described (4). In open subluxations, the intervertebral disc is open towards the side of lateral displacement. This pattern results in contralateral lateral recess and foraminal stenosis in the curve concavity. In closed subluxations, the intervertebral disc is impinged towards the side of lateral displacement. This type demonstrates an ipsilateral pattern of stenosis (*Figure 2*).

Surgical treatment might be considered in patients with significant low back and leg pain if conservative treatment fails. Severe or progressive deformity with trunk imbalance represents and indication for instrumented deformity correction and spinal fusion (5,6). In severe scoliosis with sagittal malalignment, Smith-Petersen or Ponte osteotomies might be indicated if the intersomatic space remains mobile, whereas an asymmetric pedicle subtraction osteotomy (PSO) might be used in severely rigid deformities (7). It has been demonstrated that surgical treatment of adult scoliosis can improve QoL in the mid- and long-term (8). Nevertheless, a broad range of surgical techniques exists, and patient-specific planning has to take several factors into account: age and clinical health status, comorbidities, and the 3D spinal deformity itself (9).

ASD surgery has increased in the aging population within the last decade despite relatively high complication rates. The overall incidence of postoperative complications is reported to be between 13% at 1-year follow-up and 30% at 5-year follow-up (8,10). Mechanical complications represent the main reason for reoperation, and their incidence among all complications is reported to be between 30% and 40% (11,12). The most common failures related to thoracolumbar instrumentation, including the lumbosacral junction and pelvis, are non-union and rod breakage as well as proximal junctional kyphosis (PJK) and pedicle screw loosening. It is therefore mandatory to complete accurate benefit-risk assessment and preoperative planning to avoid instrumentation failure, which negatively affects clinical outcomes in the event of multiple revision surgeries (13).

This review will describe the principles of surgical management of adult scoliosis using either minimal invasive surgery (MIS) or classic posterior deformity correction and instrumentation combined with anterior interbody fusion. Specific aspects of non-union and PJK will be emphasized and avoidance strategies of mechanical complications will be outlined.

MIS

The past decade has seen major advances for treating ASD using MIS techniques. Minimal invasive techniques usually combine posterior percutaneous instrumentation and anterior retroperitoneal approaches using interbody fusion cages. This combined MIS approach has the advantage of sparing paravertebral muscle dissection, minimal blood

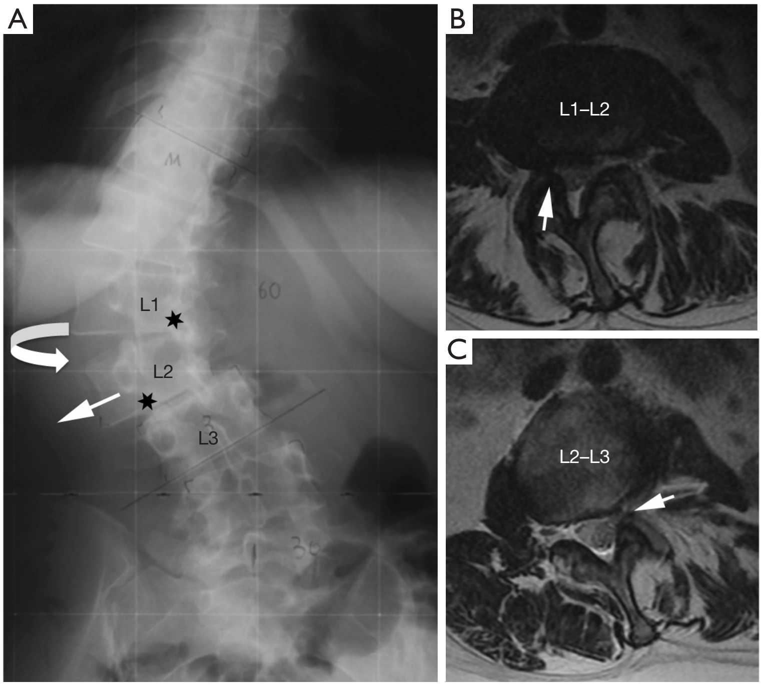

Figure 2 (A) Posterior-anterior lumbar radiograph showing vertebral rotation at L1–L2 with disc opening towards the curve convexity and lateral subluxation at L2–L3; stars indicate levels of stenosis; (B) axial MRI showing lateral recess stenosis at L1–L2, open subluxation and (C) foraminal stenosis at L2–L3, and closed subluxation. MRI, magnetic resonance imaging.

loss, and shorter operative time compared to open surgery. Experienced surgeons are treating older and more morbid patients with similar outcomes in mild and moderate spinal deformities (14). Sagittal deformity correction mainly relies on powerful interbody reduction methods that imply a resection of the degenerated intervertebral disc and anterior longitudinal ligament. Coronal plane deformities with asymmetric interbody spaces can also be corrected by lateral cage insertion, thus orientating vertebral endplates in parallel. At L5–S1, anterior interbody lumbar fusion (ALIF) cages with a large footprint are used, which creates lordosis at the lumbosacral junction. At the levels from T11–T12 to L4–L5, oblique lateral interbody fusion (OLIF) or extreme lateral interbody fusion (XLIF) cages are used. With the OLIF technique, the psoas muscle is reclined, including the femoral nerve, whereas the XLIF technique requires electromyography monitoring to detect the nerve as the approach is made through the psoas muscle (15,16).

Segmental intervertebral height increases and lordosis restoration produces an indirect decompression of spinal stenosis at the level of the lateral recess by tethering the bulging disc and flavum ligament. Furthermore, the cage implantation produces a cranial-caudal distraction of the impinged facet joints, which increases the foraminal height. This indirect anterior decompression technique enables to address open and closed subluxations without the need for an open approach to the spinal canal (17). It has been demonstrated that low back pain and leg pain improve and that the segmental lumbar deformity can be efficiently corrected with MIS techniques. (14,18). This strategy seems appropriate in mild and moderate ASD which present degenerative changes of the lumbar spine and a remaining curve flexibility (19). *De novo* scoliosis with a single or bi-level disc degeneration represents a good indication for early MIS treatment, thus preventing further curve progression (*Figures 3,4*). Severe sagittal and coronal imbalance represents a limitation for MIS. Stiff deformities that cannot be reduced on bending radiographs or that present interbody fusions on CT should be addressed by open posterior surgery including a facet joint release, osteotomies, and interbody fusion.

Posterior instrumentation

Open posterior instrumentation is based on segmental pedicle screw-rod fixation. Different correction strategies

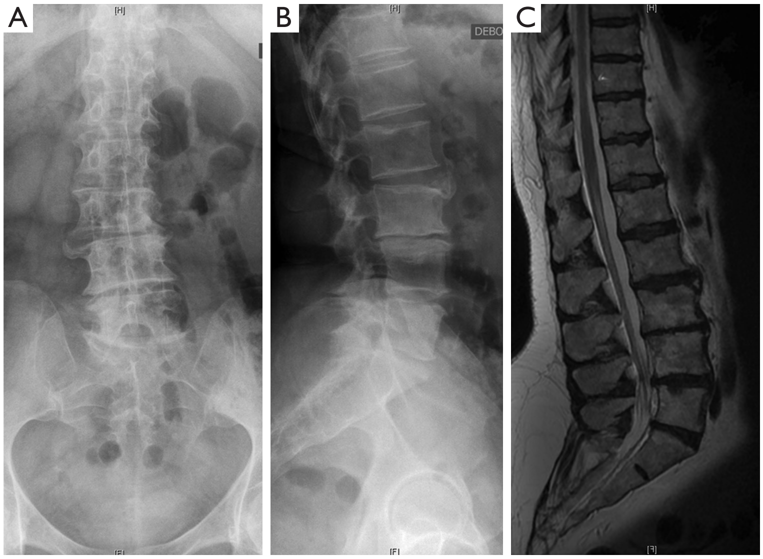

Figure 3 (A) Anterior-posterior and (B) sagittal lumbar radiographs, (C) MRI with sagittal reconstruction showing intervertebral disc degeneration and a beginning *de novo* scoliosis at L3–L4. MRI, magnetic resonance imaging.

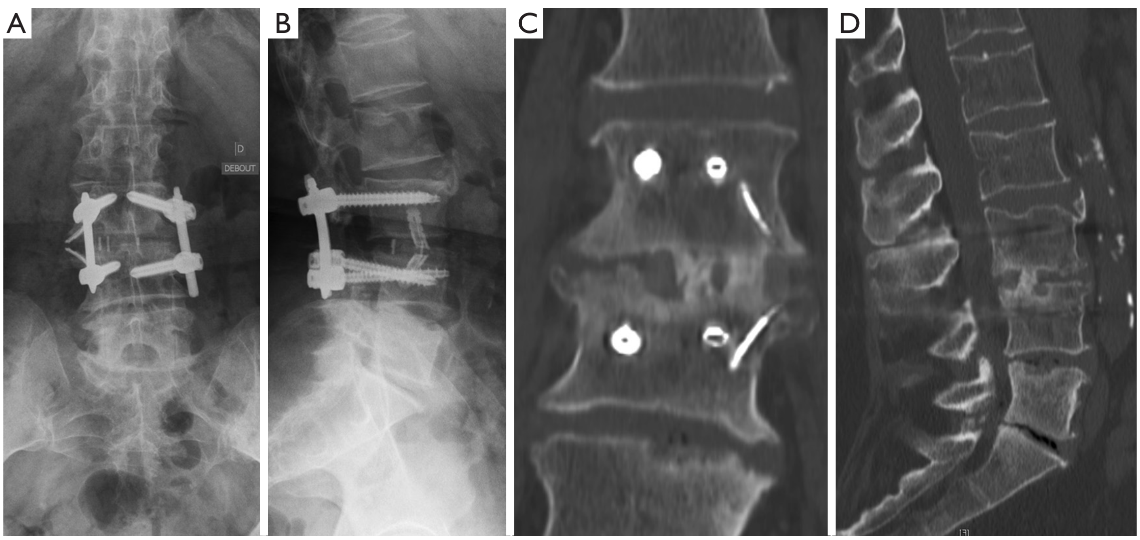

Figure 4 Postoperative (A) posterior-anterior and (B) lateral radiographs showing lumbar interbody fusion combined with posterior percutaneous instrumentation at L3–L4; 1-year follow-up CT showing interbody fusion through the OLIF cage on (C) coronal and (D) sagittal reconstructions (same patient as in *Figure 3*). CT, computed tomography; OLIF, oblique lateral interbody fusion.

exist for the reduction of severe scoliosis. Modern approaches usually combine reduction maneuvers such as direct vertebral derotation, rod translation, and approximation using persuader systems (20). In situ bending represents an additional technique that uses a rod that is first connected to the pedicle screws following the shape of spinal deformity (21). The rod is then bent by sequential maneuvers in the coronal and sagittal planes. Monoaxial screws are placed on most rotated vertebrae on the convex side of the lumbar curve. This technique will allow rotating of the lumbar apex using levers during sequential bending maneuvers of the rod and lead to a 3D correction of the deformity (*Figure 5*).

Furthermore, a preoperative analysis of residual

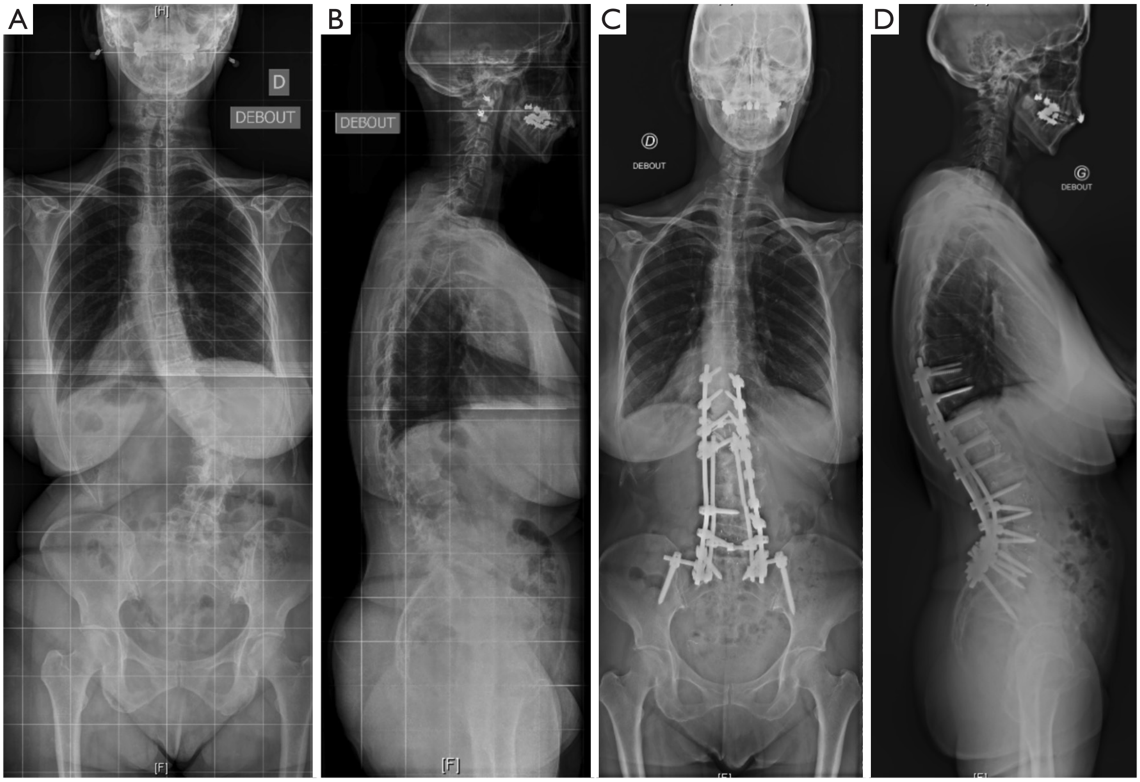

Figure 5 Preoperative (A) posterior-anterior and (B) lateral full spine radiographs of a patient with lumbar degenerative scoliosis, postoperative (C) coronal and (D) sagittal correction by posterior instrumentation, and fusion from T10 to the pelvis.

curve flexibility on side bending radiographs and CT is mandatory. A posterior facet joint release can be performed prior to correction in order to increase the flexibility of the spinal deformity. This release may be completed by Ponte osteotomies for segmental kyphosis correction. This technique may improve segmental sagittal alignment in segments that are non-fused by interbody osteophytes. Severe rigid deformities with interbody fusion areas usually require a posterior three-column osteotomy such as an asymmetric PSO (7,19,20).

Posterior instrumentation in ASD usually includes the sacrum since L5–S1 disc degeneration and facet joint osteoarthritis are present in most patients. However, the optimal distal fixation point has been a matter of debate because screw loosening might occur on long-term in long posterior instrumentation (22,23). S1 pedicle screws should follow a convergent axis into the promontorium with a bi-cortical fixation. This technique enhances the screw purchase. An additional fixation of the instrumentation at the pelvis might decrease the risk for S1 screw loosening (24). S2-alar screws represent an alternative to ilium screws thus avoiding far lateral paravertebral and gluteus muscle dissection in the sacro-pelvic area. The S2-alar screw entry point is caudal to the posterior S1 foramen, and the screw axis crosses the sacroiliac joint (25). Although the rigid sacro-pelvic fixation has decreased the risk for distal screw loosening, cyclic loading during daily activities might lead to fatigue of the posterior instrumentation, which can result in mechanical long-term complications such as non-union.

Non-union and rod failure

Non-union should be suspected if the patient is in pain and if radiographs show a rod fracture (*Figure 6*). CT combined with 99mTC-HMDP single positron emission tomography (SPECT-CT) should confirm the diagnosis (26). Posterior fusion without anterior column support might not be sufficient when instrumenting the thoracolumbar spine including the sacrum and pelvis. The lumbosacral junction may be fused by the anterior approach (ALIF), which has the advantage of a large cage surface and resistance under axial compression to avoid non-union and

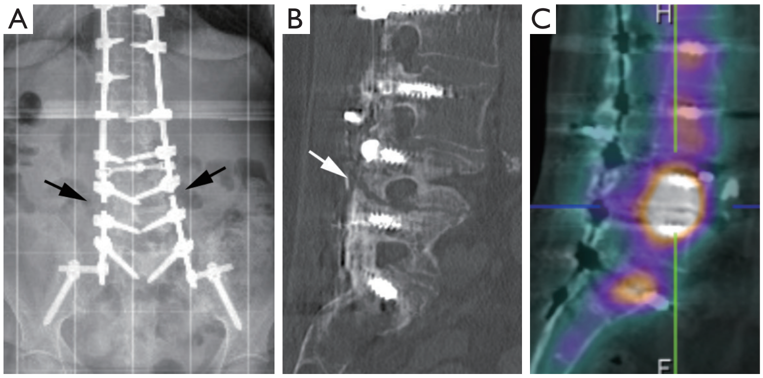

Figure 6 (A) Rod fractures on radiographs, (B) osteolysis in the fusion mass on CT and (C) hyperfixation on SPECT-CT indicate non-union. CT, computed tomography; SPECT, single positron emission tomography.

Figure 7 (A) Preoperative sagittal CT and (B) postoperative CT showing opening of the remaining L1–L2 disc space after posterior Ponte osteotomy and instrumentation. This gap needs to be filled by an anterior OLIF cage to avoid non-union. Interbody fusion has been performed using TLIF cages at L3–L4, L4–L5, and L5–S1. CT, computed tomography; OLIF, oblique lateral interbody fusion; TLIF, transforaminal interbody fusion.

subsequent revision surgery (27). The alternative would be a transforaminal interbody fusion (TLIF), which can be performed during the posterior deformity correction. Recently, dual rod techniques have been described (28-31). Their aim is to decrease strain at the level of primary rods by reinforcing the instrumentation by two additional rods when the lumbosacral junction and the pelvis are included (*Figure 5*).

Furthermore, the segmental kyphosis correction by posterior Ponte osteotomies will induce an anterior opening of mobile discs. In some cases, anterior osteophytes can break, and narrow disc spaces open up when increasing lordosis by powerful in situ bending maneuvers (*Figure 7*). It is mandatory to stabilize these segments by anterior grafting in order to prevent the loss of correction and non-union. An OLIF cage might be recommended in a second stage surgery.

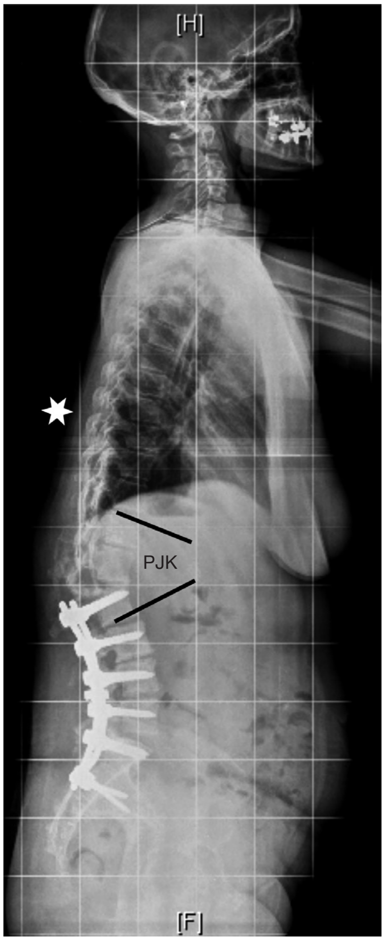

Figure 8 Sagittal full spine radiograph showing PJK due to overcorrection in a patient with low pelvic incidence. PJK, proximal junctional kyphosis.

In painful non-union revision, surgery that includes posterior and anterior fusion is usually indicated. If a rod fracture is present at one level, there is a risk for multiple level non-unions. All spinal levels should be carefully examined on imaging and tested intra-operatively in order to avoid multiple revision surgeries. In the event of a single revision surgery, the long-term clinical results can improve and the outcome might be satisfactory for the patient (8). However, the functional clinical scores decline if several revision surgeries are performed (13).

PJK

PJK represents another common complication after ASD surgery (*Figure 8*). It is defined by an increase of more than 10° of kyphosis between the caudal endplate of the proximally instrumented vertebra and the cranial endplate of the vertebra two levels above (32). Its cause is probably multifactorial. The thoracic apex and junctional vertebrae (T12–L1) should be avoided as proximal endpoints of instrumentation to avoid PJK. Furthermore, osteoporosis and osteopenia might represent risk factors for proximal screw loosening and subsequent PJK. However, a direct relationship between decreased bone mineral density and PJK has not been proven (33,34). Prophylactic cement augmentation of cranial pedicle screws and a vertebroplasty of the adjacent non-instrumented vertebral body might represent a method to avoid toggle migration of the screws and vertebral compression fractures (*Figure 9*).

Furthermore, a patient and age specific sagittal alignment needs to be considered when planning a posterior deformity correction (35). The spino-pelvic organization depending on pelvic incidence and sacral slope will influence the lumbar lordosis distribution between the upper and lower lumbar spine. Roussouly has classified the sagittal alignment into four types (36). Type 1 has a small pelvic incidence and sacral slope; the lumbar lordosis has a short caudal arch with an apex at L5. Type 2 has a small pelvic incidence and sacral slope too, but the lordosis apex is higher at the basis of L4. Type 3 has an intermediate pelvic incidence and sacral slope; lumbar lordosis is more prominent with an apex at the center of L4. A subtype characterized by an anteverted pelvis exists in this category. Type 4 has a high pelvic incidence and sacral slope with a large lordosis and an apex at the basis of L3. If the sagittal apex of lumbar lordosis is set too proximally according to the spino-pelvic organization, it is very likely that PJK occurs (37,38). The lumbar apex should not be higher than L4 if the pelvic incidence is <55°. Only patients with a pelvic incidence >55° can tolerate an apex at the L3–L4 disc or L3. Similarly, the global alignment proportion (GAP) score is based on lordosis distribution, relative lumbar lordosis and global tilt according to pelvic incidence, and relative pelvic version and age (39). In patients where sagittal alignment restoration fails, the target of proportionate lordosis distribution, the risk of PJK, and mechanical instrumentation failure increases. The Roussouly classification and the GAP score are valuable tools that should be considered preoperatively in order to determine the optimal correction strategy and sagittal profile of the instrumented spine.

Conclusions

Adult scoliosis correction provides an improvement of

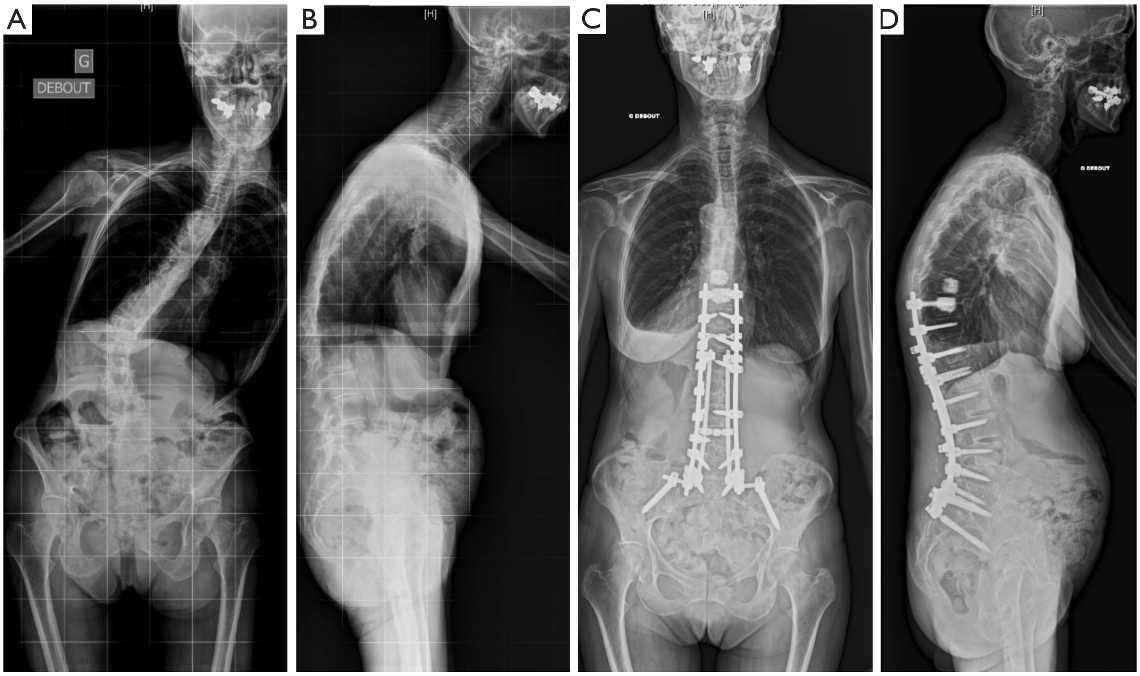

Figure 9 Preoperative (A) posterior-anterior and (B) lateral full spine radiographs of a patient with adult scoliosis and osteopenia; postoperative (C) coronal and (D) sagittal correction by posterior instrumentation and fusion from T10 to the pelvis with cement augmentation of T9 and T10 to avoid PJK. PJK, proximal junctional kyphosis.

3D thoracolumbar alignment, function, and health-related QoL. A patient-specific benefit-risk assessment has to be done preoperatively since the risk for mechanical complications is relatively high. Modern technical aspects such as circumferential lumbosacral fusion and double rods might lower the risk for non-union. Accurate sagittal alignment planning is mandatory to minimize the risk for PJK.

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None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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