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EXPERT'S OPINION

Complex osteotomies vertebral column resection and decancellation

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Abstract Pedicle subtraction osteotomy (PSO) is nowadays widely used to treat sagittal imbalance. Some complex malalignment cases cannot be treated by a PSO, whereas the imbalance is coronal or mixed or the sagittal imbalance is major and cannot be treated by a single PSO. The aim of this article was to review these complex situations—coronal imbalance, mixed imbalance, two-level PSO, vertebral column resection, and vertebral column decancellation, and to focus on their specificities. It wills also to evoke the utility of navigation in these complex cases.

Keywords Pedicle subtraction osteotomy · Sagittal malalignment · Adult spinal deformity · Vertebral column resection · Vertebral column decancellation · Navigation

Introduction

Pedicle subtraction osteotomy (PSO) is a very efficient technique for the treatment of fixed sagittal imbalance and is nowadays widely used by the spine surgeon's community [1]. It can be applied at the different levels of the spine depending on the pathology, with special precautions that are related to the area where it is performed (lumbar, thoracic, or cervical spine).

The ideal indication for a simple PSO is a pure sagittal imbalance, in a patient with a stiff spine due to ankylosing spondylitis, postoperative flatback, or pure arthrosis. But when the imbalance is in the coronal plane, or when it is an association of coronal and sagittal imbalance, the situation becomes more complicated, with different rules that need to be applied. Also, when the degree of the imbalance is very important, or the angulation is sharp, performing a single PSO may not be enough to obtain a satisfying result; in such case, the solution would be to perform either multiple PSO's or a vertebral column resection (VCR) or a variation of the latter that is a VCD. In addition, when the case is a revision surgery, which is very frequent, or when the osteotomy site is at the level of the high thoracic area, the navigation is a very useful tool to guide the surgeon in a zone that has been modified by the multiple previous surgeries, or when it is mandatory to put screws in the lower cervical spine or the cervicothoracic junction in a vicious position because of the deformity.

In this review article, we will focus on the specificities of complex malalignment situations encountered in spinal deformity surgery.

Pure coronal imbalance

Pure coronal imbalance is a rare entity, and it is usually seen in congenital cases that have been operated or not, but also in patients that have undergone several surgeries, either for deformity or for severe trauma. Correction of the coronal imbalance requires an "asymmetrical" PSO [2]. The surgical technique for this kind of osteotomy is different than the one for a classical PSO as the main principle is lateral wedge resection at the convexity of the deformity. Clear and wide exposure of the lateral wall of the vertebra, especially on the side opposite to the imbalance (convex side), is a key step in this osteotomy, as it gives access to the anterior cortex of the vertebra that needs to be fragilized as the hinge

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in this case is the lateral wall on the side of the imbalance (concave side) and not the anterior cortex as in a classical PSO. As it is an asymmetrical osteotomy, the amount of bone resected on the convex side is more important than the other side; therefore, care should be taken to avoid excessive resection of the bone above and below the pedicle on the concave side. Once the bone resection inside the vertebra is done, the anterior cortex should be fragilized by the use of Kerrison rongeurs and curettes, so that easy closure of the osteotomy can be done. The osteotomy closure and reduction are done on the convex side, two rods (one proximal and one distal to the osteotomy site) connected by a domino are put in place, and progressive compression on the domino is done, the two rods are gradually and gently brought toward one another which closes the osteotomy site. In the case of a thoracic osteotomy for pure coronal imbalance, the reduction technique could be completed by performing a distraction maneuver on the concave side, in addition to the compression on the convex side as previously described. The removal of the anterior cortex should be done very carefully to avoid any injury to the anterior vessels, especially at the level of L5 where the bifurcation of the iliac vessels puts them in a more lateral position.

Complex coronal and sagittal imbalance

The association of a sagittal and coronal imbalance is frequent, this is what is called a "combined imbalance" [3], and performing a PSO in such a case should obey to specific rules and techniques to avoid any aggravation of the deformity especially in the coronal plane. Two categories of combined imbalance should be differentiated depending on the coronal aspect of the deformity, the concave imbalance, and the convex imbalance. In the case of a concave imbalance, the subject is tilted toward the concavity of the main curve. In the case of a convex imbalance, there is an oblique take off at the lumbosacral junction and the subject is tilted toward the convexity of the main curve. The surgical strategy for a PSO in case of a rigid combined imbalance will closely depend on the type of the imbalance. For a concave imbalance, the osteotomy should be realized at the apex of the main curve; for a convex imbalance, the osteotomy should be done at the lumbosacral junction, to correct the oblique take off, and otherwise, if it is done at the apex of the main curve, it will aggravate the coronal imbalance creating a iatrogenic coronal imbalance (the proximal part of the body is shifted into the wrong direction far away from the center of the sacrum). The osteotomy that is done in these cases is usually an asymmetric PSO that is combining the two techniques of a classical PSO for a pure sagittal imbalance and the asymmetrical PSO for a pure coronal imbalance as described previously. In a concave imbalance, the amount of bone resected at the level of the convex pedicle of the apex vertebra is more important than the concave pedicle, closure of the osteotomy is always done on the opposite side of the imbalance, i.e., the convex side, two rods (one proximal and one distal to the osteotomy site) connected by a domino are put in place, and progressive compression on the domino is done, the two rods are gradually and gently brought toward one another which closes the osteotomy site. In a convex imbalance, the osteotomy is done at the lumbosacral junction with bigger amount of bone resected at the convexity of the fractional curve, and the principle of reduction and closure is similar to the concave imbalance case and is performed at the side opposite to the imbalance, i.e., the convexity of the lumbosacral junction (which is the side of the concavity of the main curve) (Fig. 1).

Important attention should be given during the execution of an asymmetrical PSO, when removing the bone at the concavity of the main curve, because, given the rotation of the vertebras, the identification of the lateral wall is not as clear as the opposite side, with a deeper field, which puts the segmental vessels at higher risk of being injured (Figs. 2, 3).

Major correction is needed

When the angle of a rigid deformity has exceeded the limits of a single PSO for a sagittal plane issue, or the limits of a

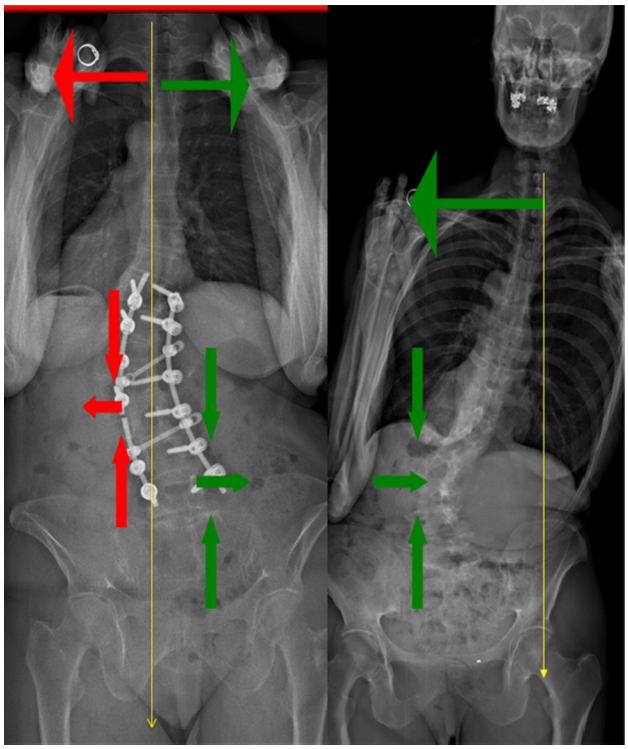

Fig. 1 Convex and concave side coronal imbalance. *On the left* convex coronal imbalance, curve correction or apical vertebra osteotomy worsens the imbalance; correction has to be realized at the lumbosacral junction to correct oblique take of the spine on the pelvis. *On the right* concave side coronal imbalance, curve correction or apical vertebra osteotomy corrects the imbalance

classical posterior release for a scoliosis, the solution would be either to perform multiple PSO's in the case of a sagittal imbalance or to perform a VCR in the case of a scoliosis or even in the case of a sharp angulated sagittal deformity.

VCR is a complex procedure with high risk of complications [4, 5]. In some cases, performing two adjacent PSO's could replace the need for a VCR with the same result, and less risks for the patient [6]. The ideal indication

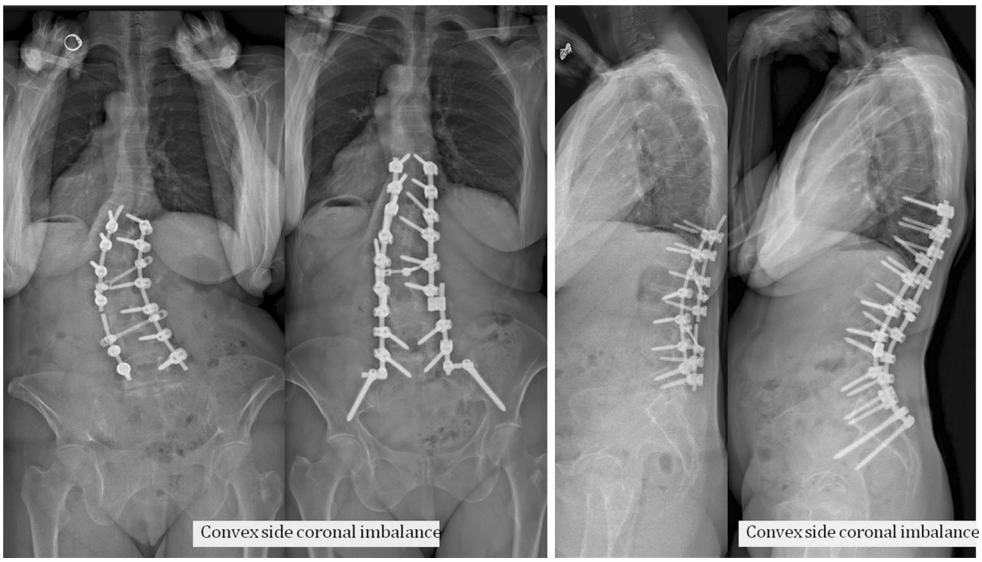

Fig. 2 Correction of convex coronal imbalance by L4 PSO; you can see the domino connector at the concave side to obtain asymmetric correction. Correction is obtained in both sagittal and coronal planes

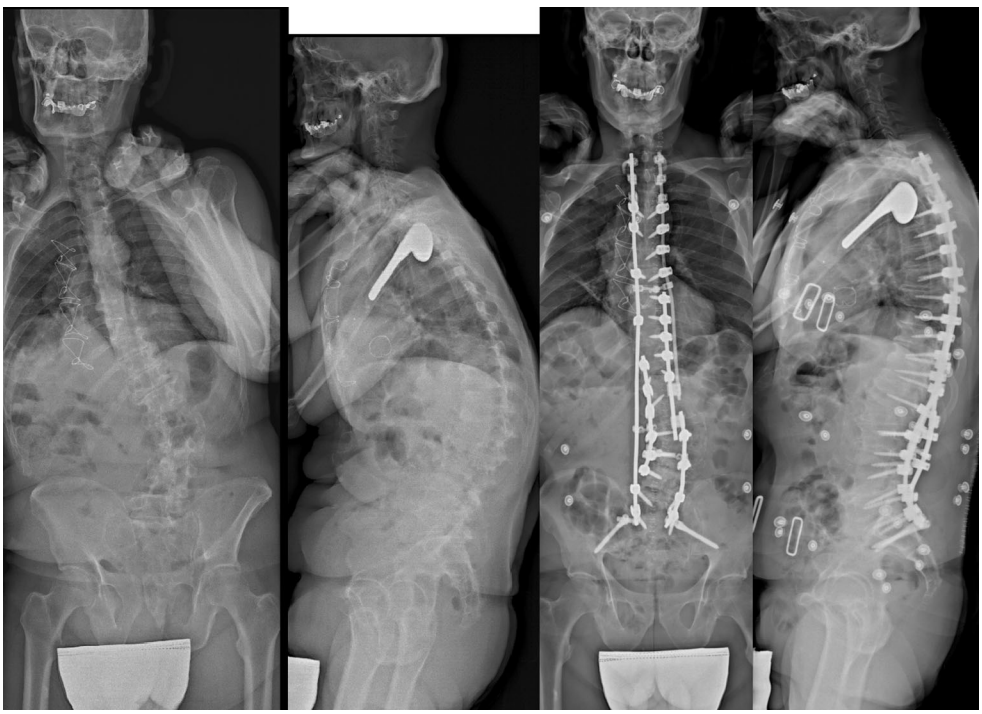

Fig. 3 Correction of concave coronal imbalance by L2 PSO; you can see the domino connector at the convex side to obtain asymmetric correction. Correction is obtained in both sagittal and coronal planes

would be a long rigid kyphosis, iatrogenic or congenital, with its apex at the thoracolumbar junction.

Two-level PSO

The execution of two-level PSO requires a good preoperative planning, because given the usual average bleeding rate for a single PSO (2,4 L) [7], it is prohibited to lose time thinking about the surgical strategy during the surgery; this could compromise the whole procedure. Thus, the PSO's levels should be clearly defined, as well as the PSO's types; it would be interesting to perform a modified PSO that includes the above disk at the proximal level, associated with a same modified PSO for the level below; this technique would remove the disk between the osteotomies site, which would enable a bone on bone contact after the closure and decrease the pseudarthrosis rate. Another variation that could be also added would be to keep the distal part of the pedicle of the distal vertebra, keeping intact the posterior arch, with no need of opening both distal foramen; this variation is interesting to decrease the bleeding rate that would come from the foramen or from the extensive opening of the canal, and extensive exposure of the dura is also avoided. As the disk above is removed, a good correction could still be reached and is not compromised by the partial removal of the pedicle. Usually with this two-level PSO technique, a correction between 60° and 70° could be done. Main advantage compared to the VCR is that there is no major instability that is created, with no need of temporary rod, and also no important defect that would require an anterior support such as a cage. In some cases, execution of two non-adjacent PSO's could be also an option (Fig. 4).

Vertebral column resection (VCR)

In front of a sharp angulated deformity, or a severe scoliosis above 100°, the only option that would enable a satisfactory result would be a VCR. VCR is a demanding and complex surgery with high neurological and vascular risks, and should be performed by experienced spinal deformity surgeons [8–11].

Surgical technique has been widely described in the literature and is as follows: After exposure of the spine, we perform posterior Ponte-type osteotomies to provide maximum release and also to aid in pedicle screw fixation. Secure pedicle screw fixation is then obtained for the appropriate levels to be included in the definitive instrumentation and fusion using the free-hand technique, and sparing the vertebras to be resected. In the thoracic spine, 5 cm of the proximal rib should be resected to access the lateral wall prior to the laminectomy. A subperiosteal

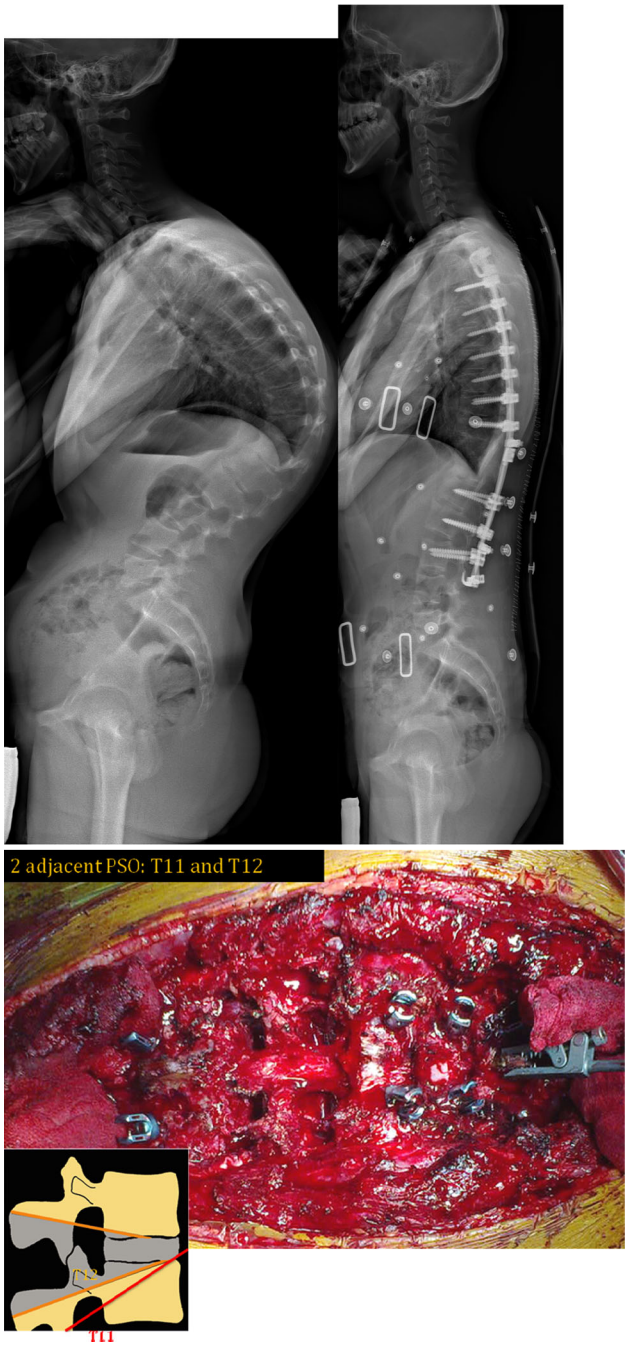

Fig. 4 Thoracolumbar major congenital kyphosis treated by 2 adjacent T11 et T12 PSO (Type 4 of Schwab) partial proximal resection of T12 pedicles allows posterior contact between T12 an L1 as shown in preoperative picture

lateral dissection is performed in order to gain circumferential access to the vertebra to be resected. A wide laminectomy is then performed, typically associating the lamina of the concerned level with the laminas above and below. Pedicles are then removed with the vertebral body. Prior to removing the anterior body, a temporary, stabilizing rod is placed and attached to at least two or three

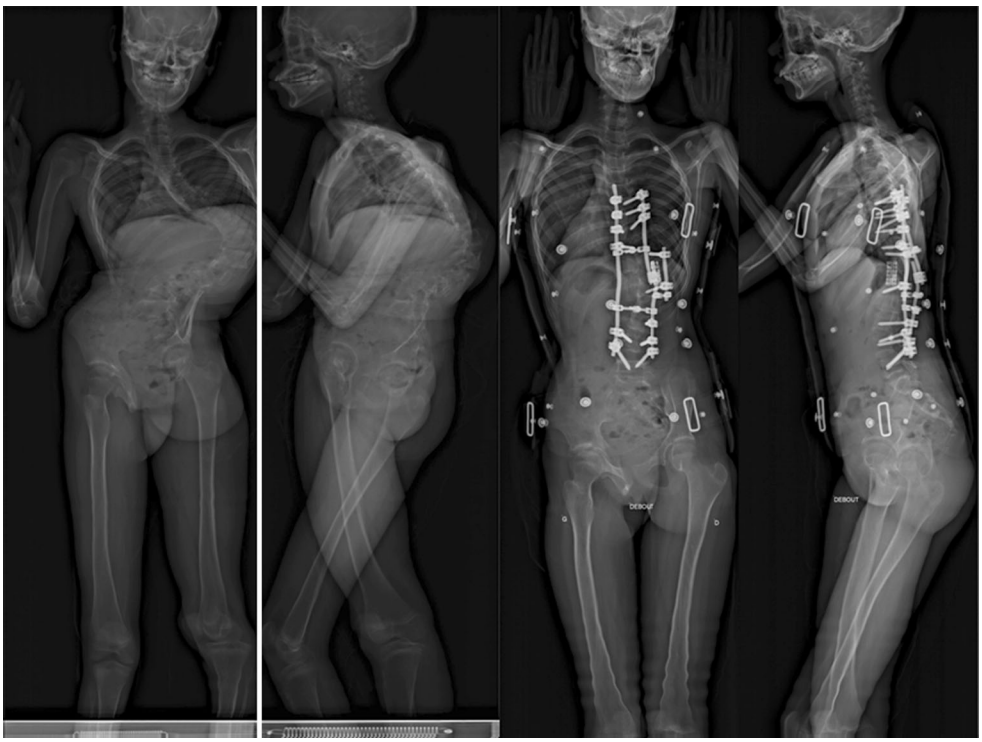

Fig. 5 Thirteen-year-old girl with neglected kyphoscoliosis, T11, and T12 PVCR allows correction in both planes. Vertebral rotation allowed anterior instrumentation by posterior approach

pedicle screws both above and below the resection area. The cancelous bone is progressively removed from the body and saved for bone graft. In a scoliosis, the temporary rod is usually put on the concave side as the major part of the resection is made at the convex side, and one should always remember that the spinal cord is resting on the concave apical pedicle. The concave pedicle is then removed carefully, with high attention to the deep vessels, and it is usually enough to fragilize it with a drill so that it can easily break. The anterior cortex is made as thin as possible but not completely removed. We then perform discectomies above and below using curettes. The last part of the vertebra to be resected is the posterior vertebral body wall. This part should be completely removed, usually with reverse-angled curettes to impale the posterior wall into the ventral defect that had been created. It is imperative that the ventral spinal cord is completely free of any bony prominences to avoid impingement during closure. For reduction, convex compression is performed. This is done by a construct-to-construct closure mechanism utilizing dominoes at the apex of the resected area after breaking the temporary rod with the first assistant holding the two parts of the broken rod. It is imperative to compress slowly as subluxation and/or dural impingement can occur at any time. In case of important kyphosis, an anterior cage should be placed to prevent over-shortening of the deformity and to act as a hinge to provide further kyphosis correction. Once closure is completed, a contralateral rod is implanted after removal of the broken temporary rod. Appropriate compression and distraction forces, in situ contouring, and other correction techniques may be performed always being mindful of any resultant effect on the resected area with respect to subluxation or dural impingement. The spine is then decorticated, and the local graft obtained from the resection procedure is put in place after covering the spinal cord with Gelfoam or a sealant to avoid direct contact with the graft and to have a continuous posterior graft (Fig. 5).

Vertebral column decancellation (VCD)

Vertebral column decancellation (VCD) is a variation of the VCR that was recently described in the literature [12]. Main difference is that it does not remove completely the vertebral body, which is less destabilizing with less amount of resected bone and no need for an anterior support. It is based on progressive decancellation of the vertebral body, i.e., removal of the cancellous bone by entering both pedicles, the cortex of the anterior and lateral walls is made as thin as possible and the posterior wall is removed, and the vertebra is made fragile so that it can collapse under pressure during the

Fig. 6 Seventh revision surgery in completely fused spine. Complete disappearance of anatomical landmarks. Navigation allowed safe instrumentation and correction osteotomy

reduction maneuver. This technique could be applied at multiple adjacent levels, and what remains of the different vertebral bodies could serve as natural anterior support cages.

Navigation

Navigation in spine surgery has been developed during the last decade and is a very useful tool in complex

deformity cases [13], and it is one of the keys that enabled the spine surgeon to push further the limits of surgical indications for complicated cases. Severe congenital cases or multi-operated cases are the ideal indications for the use of the navigation, as the anatomy has been modified, and there could be a need to perform an osteotomy inside a bone callus. The navigation can guide the surgeon through the surgical field to identify the local anatomy, which can be difficult in congenital cases; it can also show accurately the old bony structures underneath a bone callus, especially the edges of the spinal canal, to avoid any misplacement of the hardware, or any dural tear during the bone removal by misplacement of the drill. In the case of a high thoracic osteotomy for a secondary post-traumatic kyphosis or a iatrogenic kyphosis [14], there is usually an important cervicothoracic kyphosis that puts the head in a very low position compared to the rest of the body with an important difference between the level of the cervicothoracic junction and the thoracic spine; this situation makes it difficult to put cervical or high thoracic screws safely, as the classical position is completely modified by the deformity; here, the interest of the navigation to put the hardware is a key for the success of the surgery as the proximal anchorage is very important to secure the construct.

Performing a PSO in S1 is a rare condition as this osteotomy is usually performed at the lumbar levels. It finds its indication in severe dysplastic L5S1 spondylolisthesis that has been operated or not with an important kyphosis element inside the proximal part of the sacrum due to the dysplastic anatomy. In this osteotomy, the L5S1 disk should be included to have a bone on bone contact after the closure of the osteotomy site. The direction of the osteotomes should be as convergent as possible to avoid any injury to the iliac vessels, and the distal osteotome is placed just proximal to the first sacral foramen. As the sacral ala is in continuity with the S1 pedicles, a thin gap should be artificially created between these both elements to be able to close the osteotomy. Both L5 nerve roots should be controlled during the whole procedure and specially during the closure maneuvres. The navigation is mandatory in such procedure to control the depth of the instruments in the surgical field to avoid any injury to the anterior vessels.

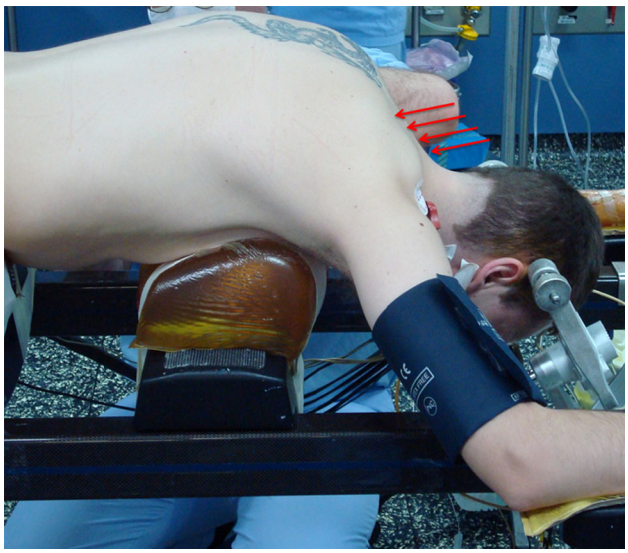

Fig. 7 Upper thoracic spine hyper kyphosis. Arrows show the direction of the pedicles in upper thoracic spine

Two major risks should be controlled during these complex surgeries: the bleeding and the neurological status. Bleeding should be managed as early as the incision has been made, with special care to the muscles, where a mild bleeding coming from a small vessel could become important after several hours of surgery. Removal of the bone and opening of the canal increase significantly the bleeding rate; here, it is essential to control epidural bleeding with the judicious use of bipolar cauterization, topical hemostatic agents such as SurgiFlow®, Gelfoam®, and cottonoids [15]. For the neurological status, during the surgery, we use transcranial motor-evoked potentials, somatosensory-evoked potentials, and free running electromyography (EMG) of the lower extremities as well as evoked EMGs with pedicle screw stimulation [16, 17] (Figs. 6, 7, 8).

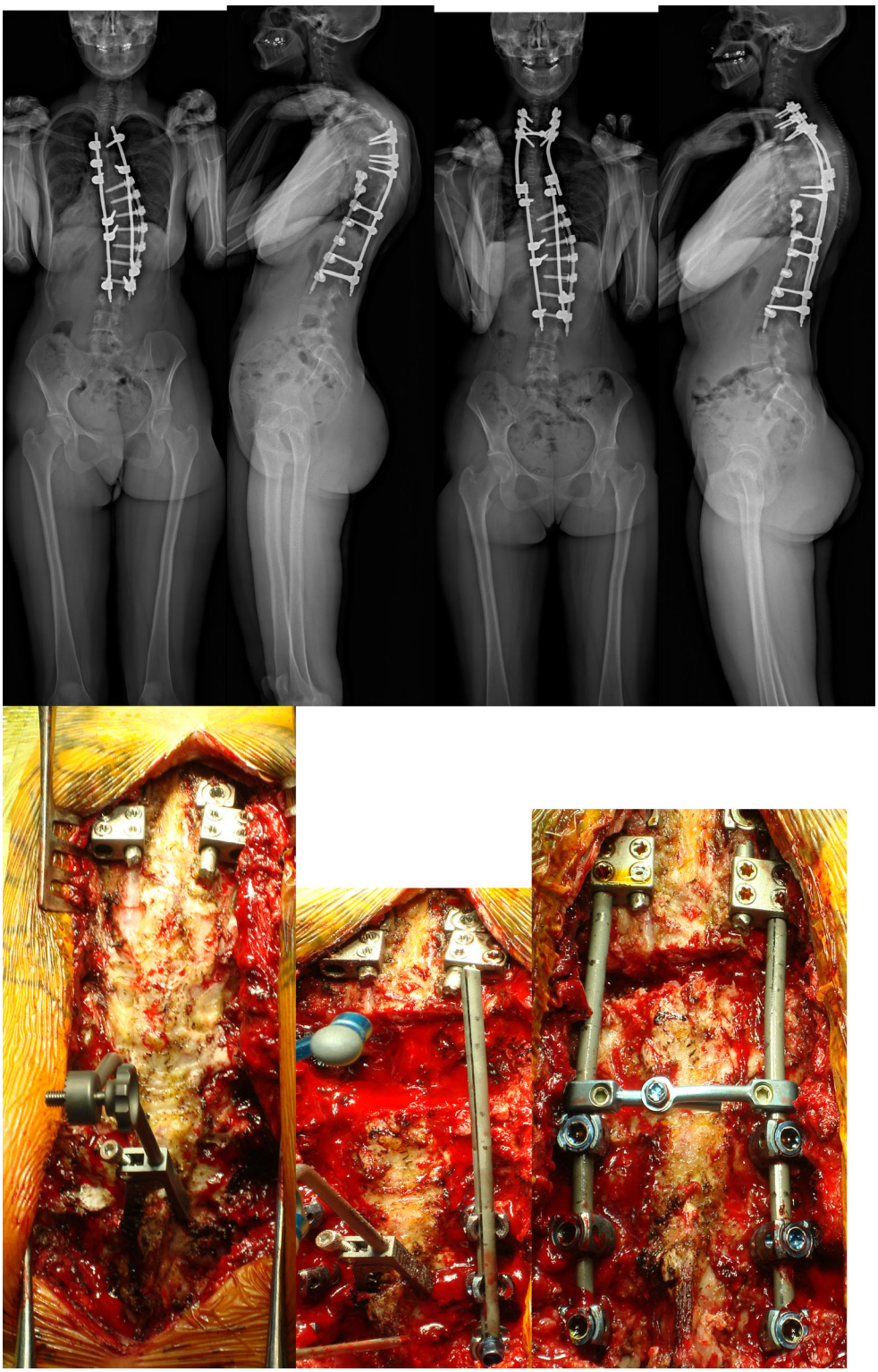

Fig. 8 Upper thoracic spine hyper kyphosis. T5 PSO, with navigation essentially to put T1 to T3 pedicle screws. Pre- and postoperative X-rays and intraoperative pictures

Conflict of interest None.

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