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IDEAS AND TECHNICAL INNOVATIONS

New method for correction of lumbo-sacral kyphosis deformity in patient with high pelvic incidence

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Abstract
Study design Technical note.
Objective We describe a novel technique of bilateral longitudinal sacral osteotomy allowing direct reduction of high pelvic incidence (PI) and correction of sagittal imbalance.
Methods A 25-year-old female patient presented with a disabling lumbo-sacral kyphosis fused in situ through previous operations with residual low-grade wound infection and grade IV L5/S1 spondylolisthesis with severity index (SI) of 65%. A two-stage correction was performed. First anterior in situ fixation of the L4–L5–S1 segments was performed using a hollow modular anchorages (HMA) screw and L3/L4 anterior interbody cage. The second stage consisted of instrumentation of the lower lumbar spine and pelvis; placement of an S1 transverse K-wire as pivot point and bilateral longitudinal sacral osteotomy which allowed for gradual retroversion of the central sacrum relative to the pelvis.
Results Sacrum was derotated by 30° which allowed to restore spinal sagittal balance and decrease SI by 15%. Postoperative recovery was complicated by a flare up of the pre-existing deep wound infection.
Conclusions Bilateral longitudinal sacral osteotomy appears to be a safe and efficient way of correcting the sagittal imbalance caused by an extremely high PI. Although technically demanding, it achieves good radiological and functional outcomes and avoids entering the spinal canal.

Keywords Lumbo-sacral kyphosis · High-grade spondylolisthesis · High pelvic incidence · Sacral osteotomy · Spinal balance · HMA screw

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Introduction

High-grade spondylolisthesis with lumbo-sacral kyphosis and high pelvic incidence (PI) poses a major challenge for maintaining physiological sagittal balance. Several authors have described different sacral and lumbar osteotomies designed to restore sagittal balance and correct the spinal deformity [1–6]. Previously, four types of pelvic osteotomies developed to deal with severe hip dysplasia and high pelvic incidence were described: Salter, modified Salter, Chiari, and posterior sacral osteotomy [1]. These technically challenging osteotomies are indicated in fixed lumbo-sacral kyphosis, especially those with high-grade spondylolisthesis, regardless of previous surgical input [4]. In the situation of a PI exceeding 90° and the endplate of S1 being oriented vertically, the sacral osteotomy methods described above require exposure of neural structures and do not easily allow correction beyond 30°. One of the methods quantifying degree of deformity caused by spondylolisthesis are severity index (SI) and unstable zone introduced by Lamartina et al. [7].

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This manuscript describes a surgical option for staged correction through in situ fusion of the lower lumbar spine to the central sacrum with reduction of PI through modified posterior bilateral longitudinal [8] sacral osteotomy and lumbo-sacral retroversion, avoiding entry of the spinal canal and pedicle subtraction.

Materials and methods

Case presentation

A 25-year-old female patient presented with a disabling lumbo-sacral kyphosis and grade IV L5/S1 spondylolisthesis (Fig. 1). The severity index (SI) and unstable zone (UZ) were calculated based on the formula by Lamartina et al. [7]. A horizontal line was drawn through the centre of S2 on a standing lateral radiograph of the lumbar spine which including the hips. Subsequently, a vertical line was drawn through the centre of the femoral heads. A second vertical was drawn through the middle of L5 inferior end plate. The distance from the centre of S2 to the vertical of the centre of the femoral heads was marked as D_2; the distance from the vertical of the middle of L5 inferior end plate to the vertical of the centre of the femoral heads was D_1. The SI was calculated as follows: SI $= D_1 \times 100/D_2$. The UZ represents are defined by the square of base defined by D_1 (Fig. 2).

The patient was unable to stand upright with knees locked, had difficulties walking independently, and was only able to mobilize using two crutches. Two previous surgical interventions elsewhere had resulted in posterior fusion from L4 to S1 with iatrogenic nerve injury of L5 and deep wound infection caused by *E. coli* necessitating partial metal work removal. The infection was presumed to be resolved following the partial removal of implants.

Surgical technique

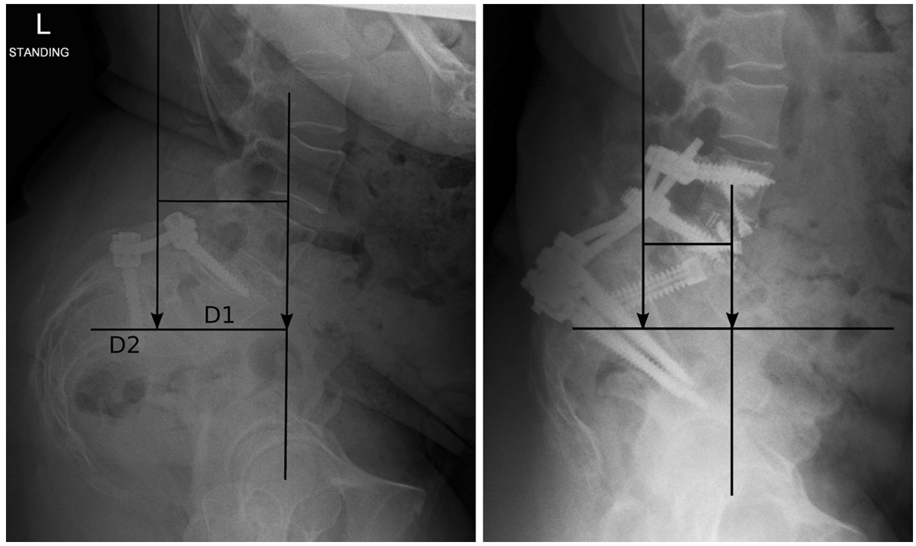
Several considerations led to the choice of the described procedure:

Pre-existing surgery and iatrogenic neural injury: as this patient had undergone previous surgery with in situ fusion and L5 injury, the prospect of conducting a conventional subtractive sacral osteotomy with the necessary manipulation of neural structures was not appealing.

The dysbalance was substantial (albeit difficult to assess precisely with conventional whole spine imaging as the patient was unable to stand upright with knees locked) with SI of 65% and UZ involving L3, L4, L5, and S1, requiring a subtractive osteotomy of the sacrum of around 30°. It was deemed simpler to "de-rotate" the sacrum via longitudinal

Fig. 1 Pre- and postoperative imaging. *Left* preoperative MRI (T2W sagittal) indicative for a high-grade spondylolisthesis L5/S1 with high pelvic incidence (PI). *Middle* preoperative standing whole spine XR showing high PI (~110°) and sagittal imbalance. Note elements of the posterior fixation after previous intervention (details in the text). *Right* Whole spine standing XR obtained 18 months after the operation. Both PI and sagittal balance improved significantly. Note elements of the anterior and posterior construct

Fig. 2 Pre- (*left*) and postoperative (*right*) diagrams showing reduction of unstable zone and severity index (SI) from 65 to 50%. The distance from the centre of S2 to the vertical of the centre of the femoral heads marked as D_2; the distance from the vertical of the middle of L5 inferior end plate to the vertical of the centre of the femoral heads marked as D_1; $\mathrm{SI} = D_1 \times 100/D_2$. The *square* of base defined by D1 represents unstable zone (UZ) involving L3 [7]



osteotomies than to attempt to achieve this with the conventional subtraction technique in a revision setting.

Given the extent of UZ, it was estimated the top level of the instrumented fusion would be L3 (Fig. 2).

Surgical stages

Given BMI exceeding 35, anticipated prolonged immobilisation and extensive surgical intervention within the pelvis following a discussion with haematology team, an inferior vena cava filter was placed preoperatively to prevent pulmonary embolism. The first stage consisted of a standard midline retroperitoneal exposure of L3/L4. Anterior discectomy was performed in the standard fashion. A hollow modular anchorage (HMA) screw was introduced centrally through the L4 vertebral body into the sacrum, terminating at the S2 level in a technique described previously [9]. A fenestration of this cage had been created using a metal-cutting burr to allow the transverse passage of a 4 mm K-wire at the S1 level (Fig. 3). This was fashioned to serve as the pivot point for the lumbo-sacral retroversion manoeuvre. An interbody cage was introduced into the L3/L4 level allowing in a view of expected appropriate fusion and preservation of the lordosis. Both cages were filled with Dibotermin Alfa (one shared pack of InductOs 12 mg; Medtronic BioPharma B.V., The Netherlands). Postoperatively, the patient was mobilised without a brace and discharged home for full recovery on a therapeutic dose of low-molecular-weight heparin to prepare for the second stage 4 week later.

The first step of the posterior procedure was to pass a K-wire transversely through the pelvis and sacrum (through the hole in the HMA screw) under fluoroscopic visualisation. This created a firm pivot point for the subsequent rotation of the sacrum (Figs. 3, 6). An inverted U-shaped skin incision was chosen extending from the iliac crest on either side with the apex at L3, which allowed for a large skin flap to be mobilised distally to the level of the sciatic notch with retraction. The paravertebral muscle complex was detached from its sacral origin bilaterally and lifted cranially in the fashion of muscle flaps. This provided excellent exposure to the entire lumbopelvic region without the usually substantial retraction required through the standard midline incision (Fig. 4). Two pelvic screws were placed on either side adjacent to the traversing K-wire. The existing lumbar pedicle screws were removed. Multiple samples were taken for microbiological analysis to assess for persistent low-grade infections despite unremarkable intraoperative findings. L3 and L4 were subsequently instrumented with fenestrated screws and augmented with PMMA in anticipations of substantial reduction forces being required (which turned out to be unnecessary as the reduction forces were low). The sacral osteotomies were performed longitudinally with a high-speed burr in the mid-section of the sacral ala, strictly avoiding the neuroforamina medially and the sacroiliac joint laterally. The anterior cortex was resected with Kerrison Rongeurs, detaching the central sacrum and lumbar spine from the pelvis. The pelvic screws were connected with transverse pelvic bars and spinal rods fixed at right angles to these (Revere Addition—Globus, USA). The pedicle screws were reduced to these rods. This manoeuvre forced the lumbo-sacral spine to pivot around the trans-sacral K-wire, reducing the pelvic incidence as the central sacrum was retroverted relative to the pelvic ring. The forces required were surprisingly low and the reduction was completed easily with approximately 30° of retroversion having been achieved. A second batch of inductors was used to fill the bilateral osteotomy gaps and the implant system was tightened (Figs. 5, 6). The wound was closed in layers with

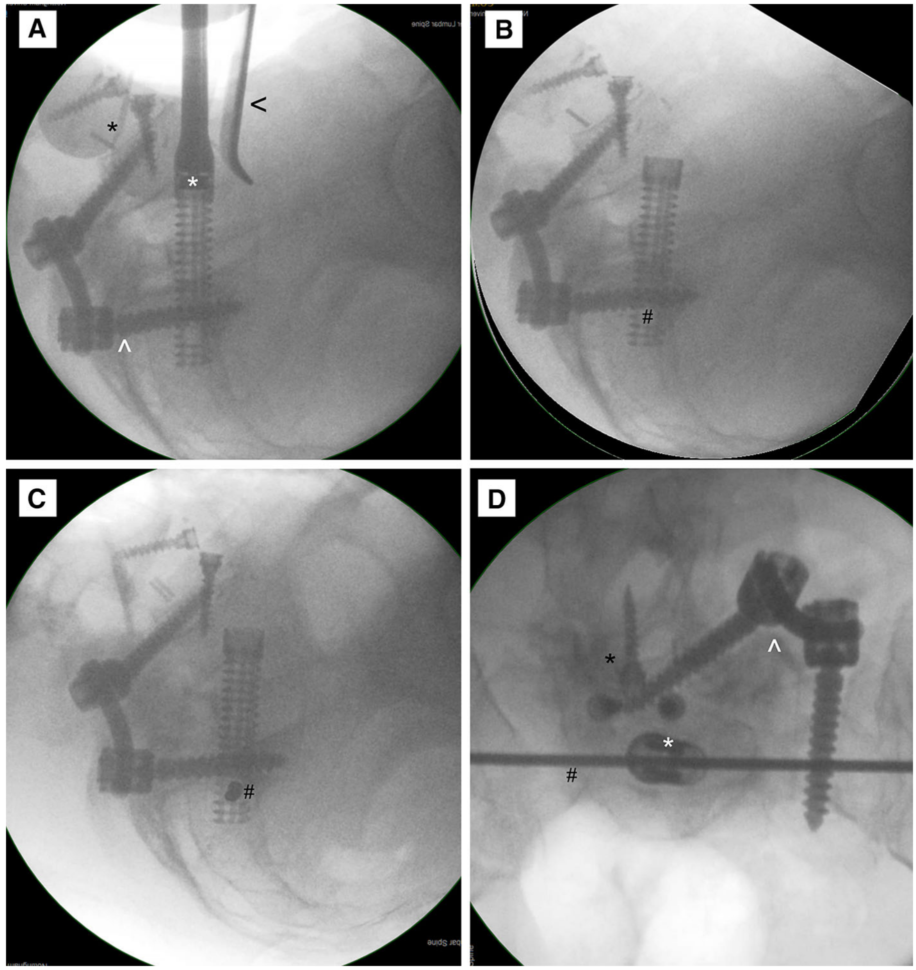


Fig. 3 Stage I of the surgical treatment—anterior approach. Intraoperative radiograms with the patient prone on the table. **a** HMA screw (*white asterisk*) is being introduced from the L4 vertebral body, passing through L5 down to S1. Note L3/L4 ALIF (*black asterisk*), blade of the Thomson's retractor (*black arrow*) and the element of the previous posterior fixation L4–S1 (*white arrow*). **b** HMA screw filled with a bone graft in its final position. Note custom made hole at the level of S1/2 (*black asterisk*). **c** K-wire passing the L4 and L5 vertebral bodies marking the trajectory for the HMA screw fixing L4–L5–S1 (*hash*). **d** AP view showing the K-wire (*hash*) passing through the HMA screw (*white asterisk*). Elements of the previous posterior instrumentation (*white arrow*) as well as the L3/L4 ALIF cage (*black asterisk*) are visible

two gravity drains under the fascia. A disposable, powered negative pressure dressing (PREVENA^{TM}, LifeCell Co., USA) was used. The second stage of the correction took 9 h; the estimated blood loss was 3000 ml. Both time spent and blood loss were contributed mostly by the sacral osteotomy.

While the procedure went uneventfully, the patient developed severe sepsis within 48 h postoperatively. An early CT scan of the pelvis did not reveal any intra- or extra-peritoneal collection or signs of bowel perforation. Despite intense antibiotic therapy and supportive treatment, the patient developed necrotizing fasciitis and emergency surgical debridement was performed. Prior to discharge the patient underwent numerous deep wound washout and debridements. During each of theatre sessions, accessible components of the metal work were also decontaminated with the use of Pulse Lavage system and 3 l of normal saline to prevent formation of the biofilm. Multiple deep microbiology swabs and tissue samples were obtained each time. Once two consecutive tests showed no bacterial growth, the decision was made to exchange the posterior instrumentation due to high risk of deep-seated bacterial colonies. Plastic surgeons were involved in the majority of wound washouts and also performed the definite wound closure. The *E. coli* isolated from blood stream and deep tissue samples had the same pattern of antibiotic resistance as which caused her sepsis 3 years earlier. Therefore, we assumed it to be the same organism which raises the possibility of deep-seated infection that has been re-activated following subsequent surgery.

The K-wire was extracted 4 weeks after the second operation once union across the osteotomy was assumed to be adequate.

Results

At 1-year follow-up, the patient posture is significantly improved with upright stance being unproblematic and well balanced (Figs. 1, 2). She is able to walk with only one stick required to balance the persistent Trendelenburg limp. CT follow-up revealed unremarkable fusion across the sacrum and instrumented spinal levels. The reduction of PI amounts to approximately 30°.

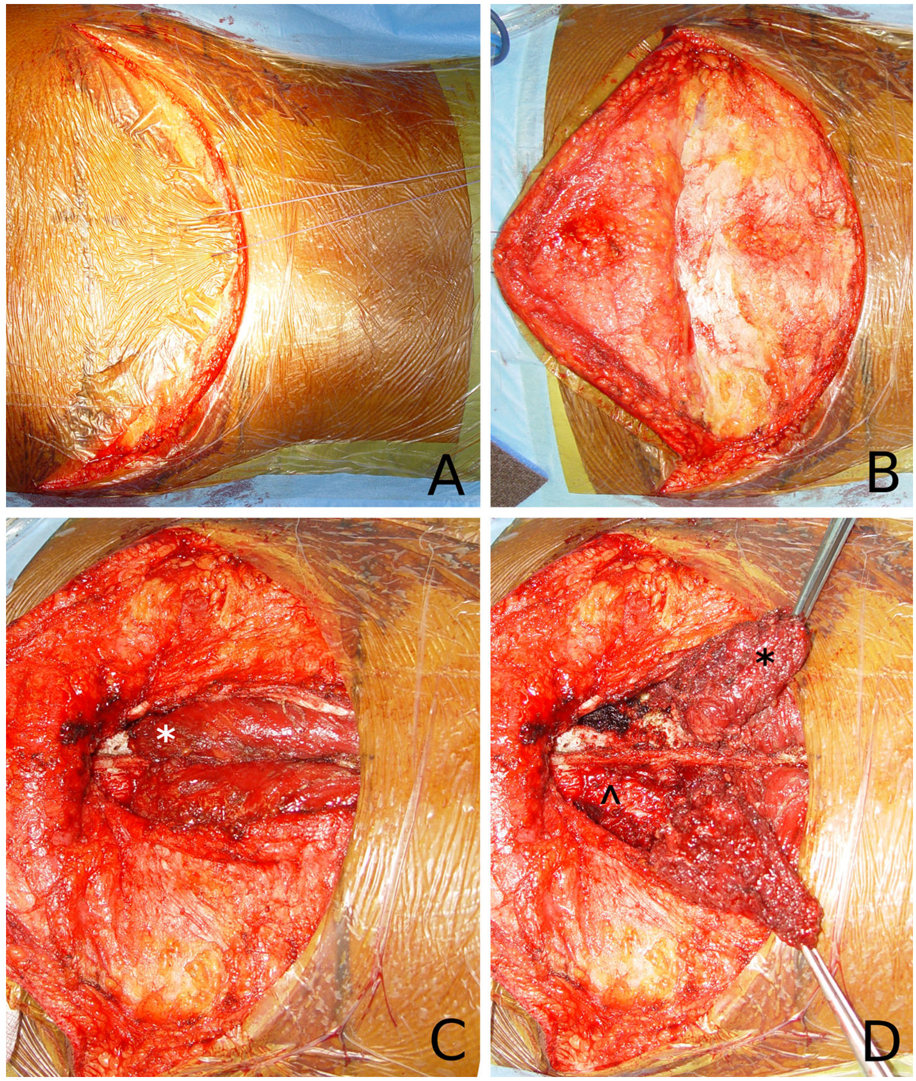


Fig. 4 Reversed "U"-shaped incision. **a** Original incision, blood supply provided by branches of superior gluteal arteries, **b** skin and subcutaneous flap reversed exposing thoracolumbar fascial (TLF) over the sacrum and lower lumbar spine, **c** TLF opened medially, multifidus muscle exposed (*white asterisk*), and **d** multifidus (*black asterisk*) dissected from dorsal aspect of the sacrum (*black arrow*) to be used as a cover for the metalwork. *Left* caudal, *right* cranial

Discussion

Four principle methods of reducing PI through osteotomy techniques have been described in detail by Bodin and Roussoly [1]. Of these, the S1 subtraction osteotomy has gained most popularity among spinal surgeons (especially while dealing with high-grade spondylolisthesis) [5, 10]. This approach, although reasonably straightforward, is not; however, risk free and complications include neurological deficit and non-union.

In the described case—due to pre-existing spinal fixation, previous injury to the L5 nerve root and expected scar tissue tethering neural structures—an alternative was devised which avoided entry to the spinal canal and manipulation of neural structures. Leaving aside the aspect of the re-activated deep infection, the technique proved to be effective with minimal blood loss. The anterior fixation occurs through transvertebral placement of the threaded cage into the sacrum and does not require direct exposure of the lumbo-sacral junction. As such, it is technically reasonably simple to perform. In our case, HMA cage appeared to be the sensible and fairly straightforward option of obtaining solid fixation (initially) and fusion (eventually) due to previous injury to L5 nerve root preventing us from re-entering the spinal canal. Another considerable option was to perform ALIFs at L4/L5 and L5/S1 which was recognised technically impossible due to the unfavourable configuration of pelvis and sacrum—pubic symphysis would not allow to access both disc spaces from the front. The posterior exposure via inverted U incision allowed for good access both the spine and pelvis—elevating the paraspinal muscles from their origin at the caudal pole of the sacrum spared, these from the usually traumatic dissection experienced during midline exposures. They also provided good implant coverage once refastened to the sacrum (via simple resorbable sutures). The exposure of the sacrum is excellent and the osteotomies themselves

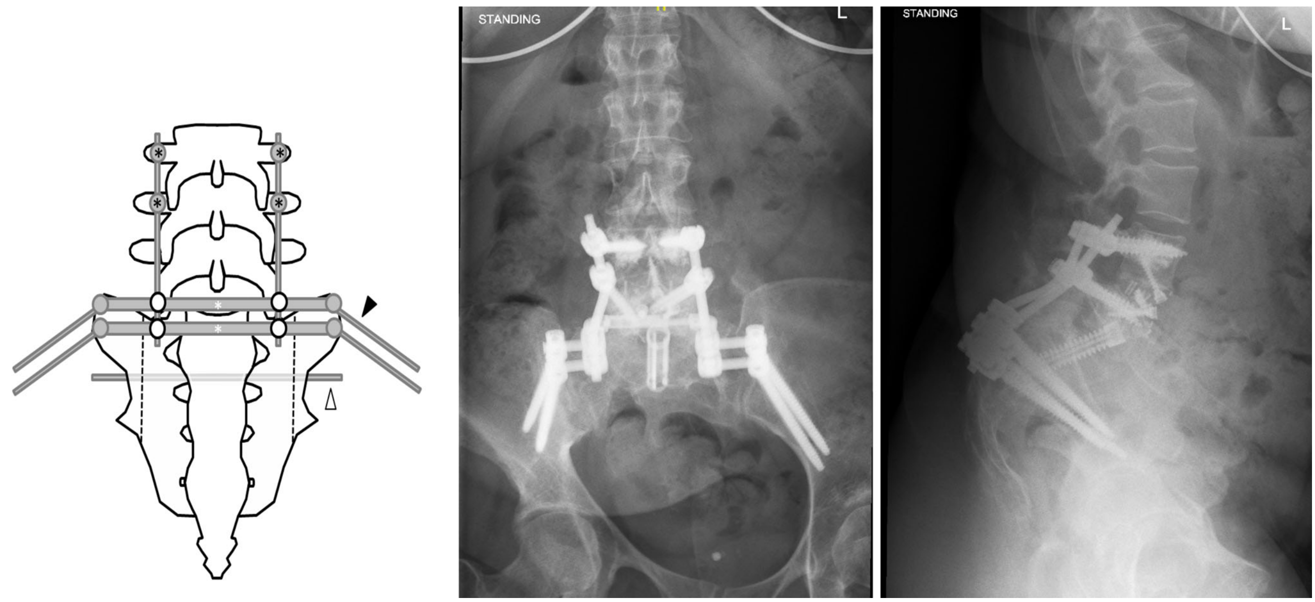


Fig. 5 Schematic of the vertical osteotomies (*dotted lines*) and posterior part of the metal construct. Rods attached to the L3 and L4 transpedicular screws (*black asterisks*) were attached (*white circles*) to the transverse bars (*white asterisks*). These in turn were connected to the iliac bolts (*black arrow*). This construct fixed the lumbar and sacral spine to the pelvis following the osteotomy and positional manipulation. Note the K-wire (*white arrow*) passing through the HMA screw and sacrum. *Middle and right* AP and lateral XR view of the construct. Note that the K-wire has been already retrived

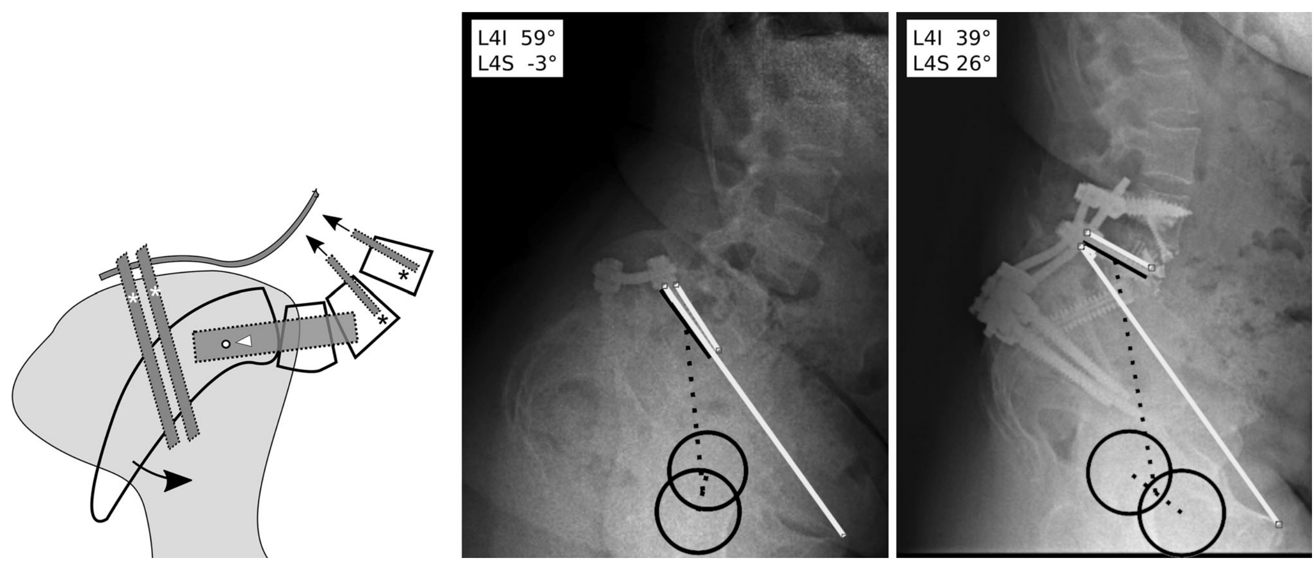


Fig. 6 Scheme of the mechanics applied while de-rotating the sacrum subjected longitudinal osteotomies. K-wire passing through the sacrum and HMA screw was a pivot point (*white arrow*) for the rotation driven by tightening of L3 and L4 screws (*black asterisks*) to the rod attached to pelvic bolts (*white asterisks*). Measurements of the spino-pelvic parameters on the pre- (*middle*) and postoperative (*right*) XR. Due to obscured anatomy of the L5/S1 area, “L4 incidence” (L4I) was measured using L4 transpedicular screw as a topographical landmark (the same hole and trajectory used). It demonstrates the rotation away from the pelvis by roughly 20°. Another parameter used was the angle between L4 and pubic symphysis (L4S) showing de-rotation by 30° contributed most likely by the reduced pelvic tilt

pose no major technical challenge. More recently, we have used the ultrasonic bone scalpel technology for (resective) sacral osteotomies which are preferable to burrs. The technically most challenging aspect is the placement of the K-wire through the hole in the anterior cage. The anatomical landmarks for trans-sacral implant placement have been described though, and with good imaging, this is readily achievable [9]. We believe that it is probably necessary to create an axis about which the retroversion can be achieved—without this, it seems likely that a free-floating sacrum would most likely only translate without retroversion. We have, however, not done work to evaluate this experimentally and cannot conclusively state that placement of an axis is necessary. While the hole in the HMA cage served its purpose well for us—which was to fix the position of the axis in place and prevent the K-wire from cutting through the sacral bone during the reduction manoeuvre—the forces exerted were lower than expected and it may suffice to place a K-wire (or screw) across the pelvis and sacrum without a reinforced pivot point.

Placing K-wire supplemented with a 'SureTrack' device in a desired position would be certainly easier if the 3D navigation based on the intraoperative CT was used. In addition, sacral osteotomy cuts might be done quicker and safer if only cutting device (burr or bone scalpel) was equipped with a navigation tracking device. Due to lack of well-defined topographical landmarks in the are of sacral cuts and anticipated inaccuracies related to the challenging 'registration', we abandoned the idea of using navigation based on the preoperative imaging. Unfortunately, navigation system utilizing intraoperative CT scans was not available at the time of performing the procedure, but would be certainly used by us while dealing with a similar case in the future.

We, therefore, conclude that although challenging, the technique introduced appears to be safe and efficient in restoring sagittal balance in selected cases of extremely high PI. The inverted U-shaped incision provides excellent exposure with minimal blood loss.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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