Sacrum osteotomy to change pelvic parameters: Surgical technique and 3D modeling

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ABSTRACT

Purpose

Some clinical situations, such as great sagittal imbalance, high-grade isthmic spondylolisthesis or sacral malunion could require a sacral osteotomy to decrease pelvic parameters, horizontalize the sacrum or correct sacral malunion. Here is described a novel technique to perform a sacral osteotomy to decrease pelvic parameters with a lumbo-pelvic construct, with first a sacral slope decrease, then a pelvic tilt decrease.

Methods

Simulations have been performed using tridimensional reconstructions of the lumbar spine and pelvis, made from CT-scan images of a healthy individual. A cadaveric study has then been performed.

Results

3D modeling exhibited linear relationship between osteotomy angle and pelvic incidence correction, through multiple simulations with 1° increment. Cadaveric study demonstrated feasibility.

Conclusion

This preliminary work shows that this technique is efficient to decrease pelvic parameters. A linear relationship has been exhibited between osteotomy angle and PI decrease, as per the following formula: osteotomy angle = PI change/0.84.

KEYWORDS

Sacrum osteotomy; pelvic parameters; pelvic incidence; sagittal alignment

INTRODUCTION

These past years, sagittal balance has been an increasing concern for spine surgeons, especially regarding deformity correction [1,2]. Relationship between pelvic parameters and morphology of the spine has been demonstrated and is now commonly admitted [3].

Some clinical situations, such as great sagittal imbalance, high-grade isthmic spondylolisthesis or sacral malunion could require a sacral osteotomy in order to decrease pelvic parameters, horizontalize the sacrum or correct sacral malunion.

Here is described a novel technique to perform a two-stage sacral osteotomy to decrease pelvic parameters with a lumbo-pelvic construct, with first a sacral slope decrease, then a pelvic tilt decrease.

SURGICAL TECHNIQUE

Patient is in prone position, ideally on an orthopedic table. Posterior median approach extends from L3-L4 level to S2-S3.

First stage: Decreasing Sacral Slope

The first stage of the surgical technique consists in implanting pedicle screws in L4, L5 and S1. A Smith-Petersen-type osteotomy and a discectomy are performed at the L5-S1 level in order to allow greater motion during later maneuvers. Two temporary rods are then put in place before achieving a distraction maneuver, which is locked by tightening the locking screws. This distraction creates kyphosis in the L5-S1 level thus decreasing sacral slope. It is mandatory to lock this distraction so the closing effect of the osteotomy to be performed is not transmitted to L5-S1 causing lordosis thus sacral slope increase. Two iliac screws are then implanted in both iliac wings.

Second stage: Decreasing Pelvic Tilt

Once the implants put in place, a complete laminectomy of S1 and S2 is performed, that allows locating and protecting neurological structures: dural sack, S1 and S2 nerve roots. This osteotomy procedure is risky and must be performed after thorough preparation because of the numerous noble structures that surround the sacrum.

Indeed, there are the sacral nerve roots exiting the sacrum through the anterior foramens, L4 and L5 nerve roots located on the anterior aspect of the sacrum alas and sacro-iliac joints. Regarding blood vessels, there are the common iliac vessels on the superior part of the sacrum alas and, lower, the internal and external iliac vessels.

The osteotomy is then performed using a bone chisel, starting with the two transversal cuts. It is a PSO-type osteotomy (Pedicle Substraction Osteotomy), more common in lumbar spine surgery, with anterior apex and posterior basis. The angulation between the two cuts is determined according to the correction needed. The second part of the osteotomy consists in performing two vertical cuts. These cuts start at the basis of the S1 facets on the external aspect, and end at the distal transversal cut, on the internal aspect of the sacral foramens. S1 and S2 nerve roots must be individualized and dissected far enough anteriorly in the sacral foramen as they can be injured during this procedure.

The sacral body is then emptied between the two transversal cuts and the anterior cortical hinge is cautiously ruptured. There is now an experimental “U-shape” sacrum fracture and a lumbopelvic disjunction.

The osteotomy is then closed, using the orthopedic table by moving hips in extension, as well as using the ancillaries classically used in spine surgery to put contraction between pelvic construct (double iliac anchorage) and the spinal one (L4-S1 screws). Thanks to the instrumentation going up to L4, it is possible to close in compression using a domino connector. Thus, by contracting posteriorly on the osteotomy site, pelvic tilt decreases through a posterior shift of the femoral heads. After the osteotomy closure, the L5-S1 level can be contracted to increase lordosis.

3D MODELING

<u>Osteotomy simulation</u>

In order to confirm our hypothesis, we first performed tridimensional reconstructions of the lumbar spine and pelvis, made from CT-scan images of a healthy individual (SolidWorks, v. 2016). We were then able to simulate she sacral osteotomy that has been planned, step by step, as follows:

a) <u>Initial parameters</u>

This is the tridimensional model used, at t0 (**Figure 1**). Pelvic parameters values (pelvic incidence (PI), sacral slope (SS) and pelvic tilt (PT)) were as follows:

PI= 38° / SS= 31° / PT=7°

b) <u>After distraction in L5-S1</u>

View of the pelvis after distraction at the L5-S1 level. The transversal cuts are also represented, randomly set at 25° (**Figure 2**).

PI= 38° / SS= 25° / PT=13°

c) <u>Posterior view of the osteotomy</u>

This is a posterior view of the sacrum representing the vertical cuts of the osteotomy, starting lateral to S1 pedicles and ending medial to dorsal sacral foramens (**Figure 3**).

d) <u>Pelvis after the osteotomy</u>

This is the final image after sacral osteotomy contraction (**Figure 4**). The goal of decreasing pelvic incidence, and all pelvic parameters is achieved.

PI = 20° *(-15°)* / SS= 25° *(-6°)* / PT= -5° *(-11°)*

Mathematic formula

Same CT-scan images of a healthy low-PI individual were used to define a new two-dimension pelvis. Initial pelvic parameters were increased manually to obtain a high-PI pelvis, closer to the indications of performing the osteotomy, and geometrical constraints were fixed in the baseline 2D model to avoid manual measuring for each sacral osteotomy angle (SOA) increment and associated bias.

Several osteotomies with various angles have been simulated using this two-dimension pelvis defined by the following pelvic parameters: a pelvic incidence of 70°, a sacral slope of 52° and pelvic tilt of 18° (**Figure 5**). Theses osteotomies were located between S1 and S2, as described in the surgical technique. The series of osteotomies, ranging from 1 to 38 degrees, with an increment of 1°, have been simulated to assess the evolution of PI in relation to sacral osteotomy angle.

A linear relationship was observed between PI and SOA, according to the following equation:

$$\mathbf{PI_F = -0.84.SOA + PI_0}$$

With: *PI_0: the initial pelvic incidence* *PI_F: the resulting pelvic incidence*

There was a strong relationship between this linear model and values observed after simulation, with an R^2 of 0.9993. A calculation of the error was performed for each simulated osteotomy based on the calculation of PI_F with the linear equation and the actual measured values. The mean error measured was 1.06% with a standard deviation of 0.44.

The relevant parameter for surgical planification being the SOA, the equation to use to plan sagittal balance improvement is the following:

$$\mathbf{SOA = \frac{\Delta PI}{0.84}}$$

With ∆PI: the desired PI variation.

CADAVER STUDY

The osteotomy previously described has then been performed on a cadaver. Implants have been set in place after exposure (**Figures 6a** and **6b**). Then, the Smith-Petersen osteotomy and discectomy at the L5-S1 level were performed (**Figure 7**). After isolation of the neural elements (**Figure 8**), the horizontal cuts were made (**Figures 9a** and **b**). The vertical cuts were then performed, by protecting L5, S1 and S2 nerve roots (**Figure 10**). The rods and connectors have then been set and contraction was performed thus achieving osteotomy closure (**Figure 11**).

Videos of contraction and distraction of the osteotomy site show interesting mobility resulting from the osteotomy.

DISCUSSION

Several pelvic osteotomies have already been described. Certain techniques were initially designed in pediatric surgery in the treatment of hip dysplasia such as Chiari's or Salter's [4,5]. More recently, several authors described first sacral vertebra osteotomy techniques, in a fashion similar to pedicle substraction osteotomies (PSO) performed in spine deformity corrections.

Hsieh et al. published in 2007 a PSO performed at the S2 level with a L2-Iliac construct to correct a sacrum kyphotic malunion [6]. The osteotomy extended laterally from one sacro-iliac joint to the other. The patient observed two weeks bed rest after surgery. A 23° decrease of the PI has been noted.

Ozturk et al. described, a decade later, an osteotomy of S1 with L5 lower endplate resection (the patient previously had L5-S1 ALIF cage) [7]. The technique then follows similar aspects with vertical cuts along dorsal foramens and L5-S3 laminectomy. They decreased PI by 15°.

Vanaclocha et al. published a feasibility study of S1 pedicle substraction osteotomies on 12 cadavers [8]. The biomechanical study showed greater mechanical features of the construct if an ALIF was associated, two iliac screws were implanted on each side instead of one and if an iliac transverse connection device was added. PI was decreased by 16°.

Bodin et al. published in 2014 a study comparing different pelvic osteotomies performed on patients for correction of spinal deformities: Bilateral Salter's, modified Salter's, Chiari's and S1 PSO [9]. Five patients were treated with S1 PSO, with no complications except transient L5 palsy in two patients. They concluded that the most efficient techniques were S1 PSO and then bilateral Salter's osteotomy.

The osteotomy proposed here and performed on specimen results from a thorough reflection about pelvic parameters and tridimensional reconstruction with the definition of a mathematic formula describing the linear relationship between osteotomy angle and PI change. The results of both mathematical formula and specimen surgery exhibited significant PI decrease. These results show that this technique achieves its main goal, namely decreasing pelvic parameters. The next step is to perform this osteotomy on patients to analyze its morbidity.

CONCLUSION

This preliminary work shows that this technique is efficient to decrease pelvic parameters by decreasing first sacral slope and then pelvic tilt, resulting in a pelvic incidence decrease. A linear relationship has been exhibited between osteotomy angle and PI decrease, as per the following formula: osteotomy angle = PI change/0.84

These results have to be confirmed by performing this technique on live patients.

DECLARATIONS

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Conflicts of interest/Competing interests: Pascal Khalifé is employed as a biomechanical engineer and owns shares of NovaSpine. Marc Khalifé owns shares of NovaSpine. NovaSpine does not present competing interests with the present study.

FIGURE LEGENDS

Fig. 1: Tridimensional reconstruction of the pelvis at t0

Fig. 2: Tridimensional reconstruction of the pelvis after L5-S1 distraction

Fig. 3: Posterior view representing the vertical cuts of the osteotomy

Fig. 4: Tridimensional modelling of the pelvis after osteotomy contraction

Fig. 5: 2D pelvis used to simulate a series of osteotomies

Fig. 6a: Lumbosacral junction after instrumentation

Fig. 6b: Fluoroscopic control of instrumentation

Fig. 7: View after Smith-Petersen osteotomy

Fig. 8: View of the neural structures

a: Left S1 nerve root. b: Left S2 nerve root

Fig. 9a: View of the horizontal cuts

Fig. 9b: Fluoroscopic control of the horizontal cuts

Fig. 10: View of the vertical cuts

a: right S1 nerve root. b: right S2 nerve root

Fig. 11: View before (on the left side) and after contraction (on the right side)

REFERENCES

[1] Roussouly P, Gollogly S, Berthonnaud E, Dimnet J. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. Spine (Phila Pa 1976) 2005;30:346–53.

[2] Laouissat F, Sebaaly A, Gehrchen M, Roussouly P. Classification of normal sagittal spine alignment: refounding the Roussouly classification. Eur Spine J 2018;27:2002–11. https://doi.org/10.1007/s00586-017-5111-x.

[3] Legaye J, Duval-Beaup??re G, Hecquet J, Marty C. Pelvic incidence: A fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998;7:99–103. https://doi.org/10.1007/s005860050038.

[4] Patil S, Sherlock DA. (iv) The Chiari medial displacement osteotomy. Curr Orthop 2007;21:109–14. https://doi.org/10.1016/j.cuor.2007.04.004.

[5] Schulze A, Tingart M. [Salter innominate osteotomy : Indications, surgical technique, results]. Orthopade 2016;45:659–65. https://doi.org/10.1007/s00132-016-3290-5.

[6] Hsieh PC, Ondra SL, Wienecke RJ, O'Shaughnessy BA, Koski TR. A novel approach to sagittal balance restoration following iatrogenic sacral fracture and resulting sacral kyphotic deformity. J Neurosurg Spine 2007;6:368–72. https://doi.org/10.3171/spi.2007.6.4.368.

[7] Ozturk AK, Sullivan PZ, Arlet V. Sacral pedicle subtraction osteotomy for an extreme case of positive sagittal balance: case report. J Neurosurg Spine 2018:532–5. https://doi.org/10.3171/2017.8.SPINE17550.

[8] Vanaclocha V, Vanaclocha V, Vanaclocha-Saiz A, Rivera-Paz M, Atienza-Vicente C, Ortiz-Criado JM, et al. S1 pedicle subtraction osteotomy in sagittal balance correction. A feasibility study on human cadaveric specimens. World Neurosurg 2018:1–18. https://doi.org/10.1016/j.wneu.2018.11.052.

[9] Bodin A, Roussouly P. Sacral and pelvic osteotomies for correction of spinal deformities. Eur Spine J 2014;24:72–82. https://doi.org/10.1007/s00586-014-3651-x.