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Preoperative, Intraoperative, and Postoperative Standing Lordosis After Pedicle Subtraction Osteotomy: An Analysis of Radiographic Parameters and Surgical Strategy

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Abstract

Study Design: Retrospective consecutive case series.
Objectives: The objective of this study was to investigate the relationship between intraoperative and postoperative lumbar spine measurements after pedicle subtraction osteotomy (PSO). We analyzed the amount of lordosis lost between the prone intraoperative image and the final upright standing film. The outcome of this analysis should be used in preoperative planning for osteotomy procedures.
Methods: Sixteen patients had pre-, intra- and postoperative measurements of lumbar lordosis. Pre- and postoperative measures of pelvic parameters were also determined. Comparisons were made between pre-, intra- and postoperative measures of pelvic parameters, with specific attention to lumbar lordosis correction and the loss of correction with transition to a standing position.
Results: The average pelvic mismatch between preoperative lumbar lordosis and pelvic incidence was 37 degrees whereas the postoperative mismatch measured 3.2 degrees. All patients had a significant correction of their lumbar lordosis. The lumbar lordosis showed a highly significant loss of 12.5 degrees from the intraoperative prone position to the postoperative standing position, with the average lumbar lordosis intraoperatively (67 degrees) decreasing to a standing lumbar lordosis of 54 degrees ($p < .000001$).
Conclusions: This analysis should aid in preoperative planning for sagittal global alignment correction and can reduce the chance of over- or under-correction in patients having a PSO procedure. Given the narrow postoperative target that is associated with better outcomes for patients, the loss of lumbar lordosis from prone to standing position may be a crucial variable in this planning process.

Keywords: Sagittal balance; Spinal alignment; Pedicle subtraction osteotomy; Flatback deformity; Lumbar lordosis

Introduction

Sagittal plane alignment has become a primary goal of adult deformity surgery. While pediatric scoliosis is often a disease of coronal imbalance, adult degenerative scoliosis often includes a loss of lumbar lordosis and the subsequent development of a sagittal plane malalignment. Although the sagittal vertebral axis (SVA) is a global assessment of sagittal alignment, this plumb line is dependent upon the patient's thoracic kyphosis, lumbar lordosis, and pelvic parameters. Recent articles have attempted to mathematically characterize the optimal relationship between these spinopelvic parameters [1-4]. Schwab et al. have developed an adult spinal deformity classification that includes pelvic parameters and has been correlated with health-related quality of life measures [4]. Failure to achieve this ideal relationship between pelvic parameters and lumbar lordosis has been associated with worsened outcomes, including increased rates of proximal junctional kyphosis and postoperative pain [5,6].

Osteotomies are one method of surgically increasing lumbar lordosis [7]. Osteotomies in the lumbar spine typically include either the Smith-Peterson osteotomy or the pedicle subtraction osteotomy (PSO). Although a Smith-Peterson osteotomy is able to yield about 5–10 degrees of

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lumbar lordosis, a single PSO is capable of creating 30–35 degrees of lordosis [7-9]. The PSO is therefore a powerful tool in cases that require a significant increase in lumbar lordosis. This technique does require the operative surgeon to intraoperatively determine the degree of angulation to fashion, and must also be balanced against any other osteotomies that are performed as part of the same operation.

Although the preoperative and postoperative lumbar and pelvic measurements can be easily determined by standard standing anteroposterior and lateral scoliosis views, intraoperative determination of these measurements can be quite difficult. Intraoperative imaging is typically performed via fluoroscopy, although some dedicated spine operative centers are able to obtain full-length 36″ films. Patient positioning and a prone versus upright position make it difficult to predict the eventual upright spine measurements while in the operation theater.

The objective of this study was to investigate the relationship between intraoperative and postoperative lumbar spine measurements. We were specifically interested in the amount of lordosis achieved on the operative table after a pedicle subtraction osteotomy and then the amount of lordosis lost between the prone intraoperative image and the final upright standing film. If this relationship could be determined, we might be better able to predict the final correction while in the operating room and therefore minimize the chance that patients would end up over- or under-corrected.

Methods

This series is a retrospective review of consecutive PSO cases conducted at a single institution after IRB approval. Inclusion criteria were (1) surgical procedure that included a PSO, (2) standing lateral preoperative and postoperative films that included the lumbar spine and femoral heads, and (3) use of intraoperative C-arm imaging. A total of 24 PSO cases were identified that met the above criteria. Eight cases were excluded because the intraoperative C-arm images did not include an image that allowed for calculation of lumbar lordosis, typically because the saved images included only a segment of the lumbar spine. The 16 remaining patients had suitable preoperative, intraoperative, and postoperative lateral x-ray images (see Table 1). All x-ray images were loaded into Surgimap software (Nemaris, Inc., New York, NY). The standing preoperative and postoperative pelvic parameters were measured by three examiners, including the primary author and two independent unbiased neuroradiologists (see Table 2). The measurements included assessment of pelvic tilt, pelvic incidence, and lumbar lordosis, as well as the lordosis between the superior endplate of L2 and the inferior endplate of L5. The intraoperative lumbar lordosis and

Table 1
Summary of demographic data for all 16 patients included within this study.

Baseline Characteristics	Total
Age	67.8 years (average)
Gender	8 males, 12 females
Level of PSO	
L2	1
L3	11
L4	3
L5	1
Surgical parameters	
Upper lumbar–pelvis	1
Lower thoracic–pelvis	12
Upper thoracic–pelvis	3
Quad-rod	12 (6 parallel, 6 stacked)
Dual-rod	4
Revision	8
Primary	8
Posterior alone	5
Posterior + lateral	10
Posterior + anterior + lateral	1
Previous interbody fusion	2
Single-stage	5
Two-stage	11

PSO, pedicle subtraction osteotomy.

Table 2
Imaging: Pre-, intra-, and postoperative averages, ranges, and standard deviations for the 16 patients.*

Parameter	Preoperative Average (degrees)	Intraoperative Average (degrees)	Postoperative Average (degrees)
PI	52 (35–77, ±11)		51 (32–73, ±11)
PT	28 (14–41, ±8)		20 (8–42, ±10)
LL	16 (0–47, ±13)	67 (47–88, ±11)	54 (29–76, ±13)
PI–LL mismatch	36.7 (13–61, ±12)		3.2 (−29 to 17, ±12)

PI, pelvic incidence; PT, pelvic tilt; LL, lumbar lordosis.
* PI, PT, and LL were measured twice for all patients by three examiners.

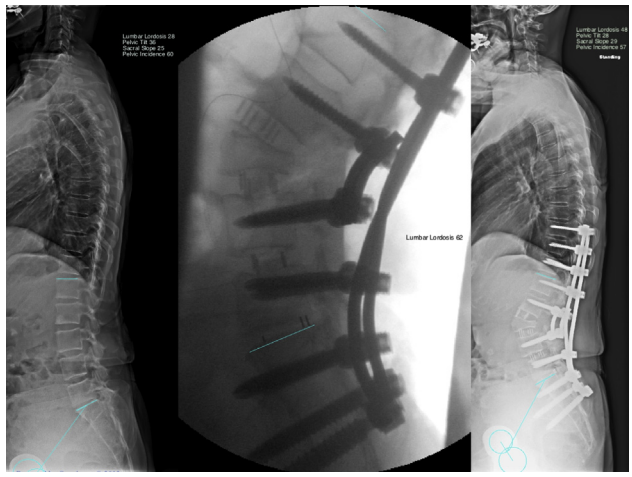

Fig. Pre-, intra- and postoperative x-ray for a representative patient. The preoperative and postoperative images were used to calculate lumbar lordosis and pelvic parameters, whereas the intraoperative image was used to calculate an intraoperative lordosis while in the prone position. In this patient, the preoperative lumbar lordosis measured 28 degrees, increasing to 62 degrees after a pedicle subtraction osteotomy at L3 and interbody graft placement at L2–L3, L3–L4, L4–L5, and L5–S1. The loss in lordosis from prone to standing position was 14 degrees, for a final standing lumbar lordosis of 48 degrees.