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Sagittal alignment in lumbosacral fusion: relations between radiological parameters and pain

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Abstract The objective of this study was to conduct a radiological analysis of posture before and after lumbosacral fusion to evaluate the influence of spinal alignment on the occurrence and pattern of post surgical pain. The study included 81 patients, of whom 51 had a history of previous low back surgery. We excluded patients with suspected or confirmed nonunion. In the fusion group, the 27 patients who were pain free after the procedure were compared to the 54 patients with residual pain. Thirty patients had pain only or primarily when they were standing immobile, 18 when they were sitting immobile, and six in both positions. Measurements were done on full-length lateral radiographs of the spine, with the patient standing according to Duval Beaupère criteria. The subgroup with postfusion pain was characterized at baseline by a more vertical sacrum with less sacral tilt (ST) ($P < 0.0062$) and more pelvic tilt (PT) ($P < 0.0160$). PT at last follow-up (PT fu) correlated with the presence of postfusion pain (NP: $P = 0.0003$). In the patients with postfusion pain, PT was almost twice the normal value. ST at last follow-up

(ST fu) in the standing position was also correlated with the presence of postfusion pain ($P < 0.0001$) indicating that the sacrum remained abnormally vertical in the subjects with postfusion pain. Using logistic regression, the only prognostic factor for residual pain at last follow-up was ST fu. Both at pre-operative evaluation and at last follow-up, patients with pain in the standing position or in both the standing and sitting positions were characterized at pre-operative status by a more vertical sacrum with less sacral tilt. The results of this study indicate that, achieving a strong fusion should not be the only goal. Appropriate position of the fused vertebrae is also of paramount importance to minimize muscle work during posture maintenance. The main risk is failing to correct or to causing excessive pelvic retroversion with a vertical sacrum leading to a sagittal alignment that replicates the sitting position. This situation is often accompanied by loss of lumbar lordosis and adversely affects stiff or degenerative hips.

Key words Sacroiliac joint · Lumbosacral fusion · Spinal alignment

Introduction

Lumbosacral fusion with instrumentation has benefited from technical refinements provided by the development of better and different internal fixation procedures [12] and of intersomatic grafting via either the posterior (PLIF:

posterior lumbar interbody fusion) or anterior (ALIF: anterior lumbar interbody fusion) approach. Now, the main problem has shifted from obtaining vertebral fusion to achieving optimal spinal alignment.

Some authors have reported harmful effects of flatback due to poorly aligned spinal fusion [1, 3, 21, 27]. Surgical

correction of such flatback deformity is difficult, with a high complication rate, making prevention a top priority.

“Normal” sagittal alignment is difficult to determine, and the optimal degree of lordosis has not yet been defined [14, 26, 32]. Although several studies have investigated normal lordosis in the standing, supine, or sitting position [4, 17], the relationships between the components of the lumbopelvic complex remained unclear until the studies reported by Duval Beaupère’s group [7].

Sagittal spinal alignment varies over time [2, 6, 13]. “Flatback syndrome” is generally described as a manifestation of aging of the spine, but the authors do not differentiate between the respective roles of lordosis loss and pelvic retroversion.

There are several reports in the literature of residual lumbosacral pain referred to the sacroiliac joints, the sacro-sciatic ligaments, and the paraspinal muscles; in some cases, the pain was projected from the thoracolumbar junction [5, 8, 9, 18, 25]. Few of these reports describe the pain as related to posture, and most place the blame primarily on changes in lumbar lordosis.

The objective of this study was to conduct a radiological analysis of posture before and after lumbosacral fusion to evaluate the influence of spinal alignment during surgery on the occurrence and pattern of postsurgical pain, independently from the classic causes of failed back syndrome (neuro-psychologic problems [28], graft nonunion, residual disk mobility, persistent nerve root compression or technically faulty internal fixation). In addition to surgery-related changes in lumbar lordosis, we studied constitutional and functional pelvic parameters.

Materials and methods

Patient

The study includes patients who underwent lumbosacral fusion and follow-up observation at the Orthopedic Surgery Department of the Pitié Teaching Hospital between February 1991 and June 1997. Of the 103 cases identified by chart review, ten were excluded because of psychopathology interfering with evaluation of surgical results, seven because of inadequate radiological documentation or possible persistent nerve root pain, and five because of graft nonunion and unavailability of the patient for evaluation other than by telephone interview.

We studied the remaining 81 patients, 49 men and 32 women, with an average age of 61 years (range 41–79 years) and a mean follow-up of 2.8 years (range 1. 2–6.5 years). Fifty-one patients had a history of previous low back surgery; among them, 47 had undergone at least two surgical procedures on their lower back.

The reason for the surgical procedure was degenerative disc disease in 44 patients, repeated surgery for herniation in 12, spondylolisthesis in 9 and failed stabilization surgery history in 16 (Table 1).

All 81 patients were positioned on the same type of operating table, with the hips flexed to 45° and the knees to 90°; a height-adjustable lumbar support was used to vary the degree of lordosis by changing the position of the iliac crests and the degree of flexion of the hips.

We excluded patients who underwent “floating” L4-L5 fusion above a normal and/or mobile L5-S1 and those who had clinical

Table 1 Indications and levels of lumbosacral fusion in 81 patients

Indication	No. of patients	L5–S1 fusion	L4–S1 fusion
Degenerative disc disease	44	17	28
Repeat surgery for disc herniation	12	6	6
Low-grade spondylolisthesis (1–2)	7	2	5
Revision of lumbar fusion	13	3	10
Revision of flexible instrumentation	1		1
Revision of ligamentoplasty	2		2
Grade 3 spondylolisthesis	2		2
	81	28	53

neurological abnormalities or other lesions of the lower limbs or spine. We also excluded patients with suspected or confirmed nonunion at last follow-up based on tomography or computed tomography findings. Nerve root pain was the dominant preoperative symptom in the 81 study patients. None of the study patients had postoperative symptoms or residual nerve root impingement visible on imaging studies; these last consisted of postoperative myelography in 13 cases, magnetic resonance imaging [MRI] in 27, and computed tomography in 48. In ten doubtful cases, sacroiliac pain was assessed with local Xylocain infiltration.

None of the patients had evidence of significant psychopathology as assessed by a neuropsychiatrist who was not involved in the study. Compensation, if any, was evaluated on a case-by-case basis.

Reference radiological parameter values were obtained from 24 patients (12 men and 12 women, with a mean age of 50 years) free of abnormalities of the spine, pelvis and lower limbs.

Methods

Clinical study

The clinical study involved two phases:

1. A group of pain-free patients with a negative history for spinal surgery, spinal abnormalities, and pelvic abnormalities was studied to obtain reference data (nonfusion group).
2. The 81 surgical patients in our series were studied (fusion group).

In the fusion group, patients with and without residual pain were studied separately [5]. In the subgroup with residual pain, the pain was located in the lumbosacral area, with no typical nerve root radiation and no exacerbation while coughing or straining. The pain usually radiated to the groin area or buttock and to the posterolateral aspect of the thigh. Painful situation was classified in three categories: pain when (1) standing immobile or (2) sitting immobile or (3) present in both positions (mixed).

Radiological study

Nonfusion patients (reference group, n = 24). Measurements were done on full-length lateral radiographs of the spine, with the patient standing or sitting with the arms folded across the chest (focal distance: 2 m). In the standing position, the patients were asked to stand straight but relaxed, with the knees as fully extended as

possible without causing discomfort. In the sitting position, the patients were positioned with the hips and knees in 90° flexion and the feet flat on the floor; again, they were asked to sit straight but relaxed, with the arms folded across the chest. The reference vertical line was the edge of the film corresponding to the edge of the cassette.

Fusion patients (n = 81). Lateral radiographs of the entire thoracolumbar spine allowed analysis of the position of the femoral heads and sacral tilting, of flexion contracture of the hips and of the lumbar curvature. Radiographs in the sitting position were also taken preoperatively in 39 patients. In 49 patients, full-length lateral radiographs in the standing position, taken before surgery and meeting above-described criteria, were available. In 32 patients only femoral heads and cervical part were visible; evaluation of superior part of the femoral shaft was not possible because of limitation induced by the patient's length.

At last follow-up after surgery, full-length lateral radiographs of the spine in the standing position were obtained for all patients.

Radiographic parameters

The analysis of lumbopelvic parameters before surgery, during surgery and at last follow-up after surgery, was based on the criteria of Duval-Beaupère [7], assessed on the standing radiographs (Fig. 1). When the femoral heads were not exactly superimposed over each other, the middle of the segment connecting the femoral heads was used as the landmark. The sacral tilt (ST) angle in the standing position was defined as the angle formed by the tangent line to the upper endplate of S1 and the horizontal plane [16]. A smaller ST angle indicates a more vertical sacrum and a larger ST angle a more horizontal sacrum. On lateral radiographs, the sitting position (Fig. 2–2) is normally characterized by a decrease in lumbar lordosis and a shift of the sacrum toward a more vertical position, resulting in pelvic retroversion. During standing, in contrast, the sacrum moves to a more horizontal position, resulting in pelvic anteversion (Fig. 2–1). We determined the ST preoperative angle (STpre) and the angle at last follow-up (STfu).

Pelvic tilt (PT) is the angle formed by the vertical plane and the line connecting the center of the sacral plateau to the center of the axis of the hips. We determined PT preoperative (PTpre) and at last follow-up (PTfu). PT is larger in subjects with pelvic retroversion and a vertical sacrum. Conversely, a markedly horizontal sacrum is associated with a small or negative PT.

Another patient-related constitutional morphologic parameter was also measured: the incidence angle (I) formed by the perpendicular line to the tangent line to the center of the sacral plateau

Fig. 1 Measurement of sacral tilt (ST), pelvic tilt (PT) and incidence angle (I) on lateral radiographs. Landmarks are the midpoint *M* of the upper endplate of S1, the plane of the upper endplate of S1 (2) and the center *H* of the superimposed hip joints (line (5) perpendicular to the plane of the upper endplate of S1). *ST* is the angle between lines 1 and 2, *PT* the angle between lines 3 and 4 and *I* the angle between lines 3 and 5. As lines 4 and 5 are perpendicular to lines 1 and 2, respectively, *ST* is also represented by the angle between lines 4 and 5, and hence $I = PT + ST$

Fig. 2 Change in sacral tilt between the standing (1) and sitting (2) position: during sitting, the sacrum moves to a more vertical position, i.e., *ST* decreases

Table 2 Angles in nonfusion reference patients ($n = 24$) (ST sacral tilt, PT pelvic tilt, I incidence angle)

	Mean	Minimum value	Maximum value	Standard deviation
ST	38.9°	32°	43°	2.7°
PT	17.9°	5°	35°	7.4°
I	56.9°	37°	76°	7.7°
Overall sitting lordosis (L1–S1)	32°	–	–	12°
Overall standing lordosis (L1–S1)	46°	–	–	11°

and by the line connecting this center to the center of the axis of the hips.

The angles that we determined are related by the formula $I = ST + PT$, which can be readily demonstrated geometrically. This formula shows that any change in ST is inevitably associated with a change in PT.

On the standing radiographs, the positions of T9, L1, L2 and L3, were calculated by measuring the angle formed by the vertical line drawn through the center of the femoral heads and the line connecting this center to the center of the relevant vertebral body.

Overall lordosis was evaluated between the upper endplate of L1 and the upper endplate of S1. Data on S1 overhang were not analyzed because of substantial variability in results due to measurement difficulties.

All measurements were done five times, during different measurement sessions, by each of three independent evaluators. The variation of the amplitude of the ST and PT angles between the sitting and standing position was calculated using these measurements to evaluate preoperative lumbosacral mobility.

Flexion contracture of the hip was evaluated only qualitatively, since reliable radiographic measurements were not available. The sacroiliac joints were evaluated radiologically before and after surgery.

Statistical methods

Statistical analysis was done using the SAS package (SAS Institute, Cary, NC, USA, 1989–1995). For comparisons of qualitative variables, either Pearson's chi-square test or Fisher's exact test were used, depending on sample size. Quantitative variables were compared either using Student's t -test after verification that distribution of the variables was normal or using the non-parametric

Kruskal-Wallis test if several groups were being compared. A multivariate logistic regression model was used to identify factors predicting postfusion pain, with the prefusion and postfusion radiological parameters as the explanatory variables.

Results

Clinical results

Twenty-seven fusion patients were completely pain free and 54 experienced residual pain evaluated with clinical examination of the ilio-lumbar angle and the sacro-iliac joints. Of these 54 patients, 30 reported pain only or primarily when standing immobile, 18 when sitting immobile and six in both positions.

Accurate data on compensation were available for 61 patients. Of the 41 patients who received compensation, 21 had postfusion pain, whereas 19 out of the 20 remaining patients were pain free after fusion, with a statistically significant difference ($P = 0.001$).

Data allowing accurate evaluation of flexion contracture of the hip were available before fusion in 49 patients and after fusion in all 81 patients. Flexion contracture was present before fusion in 13/49 patients and after fusion in 23/81 patients. A significant association between flexion contracture of the hip and postfusion pain was found ($P = 0.015$).

Evaluation of angles

The results of repeated angle measurements in the non-fusion (reference) group demonstrated satisfactory reproducibility: mean variability was 6° for measurements obtained by placing a goniometer on the radiographs (none of the radiographs were digitized). Similar variability was noted in the fusion group, although ST measurement was more difficult because of vertebral endplate remodeling.

Table 3 Angles in fusion patients ($n = 81$) (pre preoperative, fu last follow-up)

	Mean value	Minimum value	Maximum value	Standard deviation	No pain	Pain	
STpre	41.4°	13°	67°	10.3°	45.7°	39.2°	$P = 0.0062$
STfu	36.4°	10°	61°	12°	32.6°	43.8°	$P < 0.0001$
PTpre	17.3°	–16°	57°	13°	12.4°	19.7°	$P = 0.0160$
PTfu	22.2°	–12°	55°	15°	13.9°	26.2°	$P = 0.0003$
I	58.6°	39°	77°	9°			
Overall sitting lordosis (L1–S1)							
Pre-op	27°			7°			
Post-op	25°			6°			
Overall standing lordosis (L1–S1)							
Pre-op	40°			9°			
Post-op	43°			10°

Fig. 3A Lumbosacral fusion with posterior plates and a vertical sacrum (pelvic retroversion) ST = 20°, PT = 18°, I = 38° (“narrow” pelvis). The visualisation of the upper part of the femur allows qualitative determination of the standing hip flexum. **B** Large lateral views. Note how small the adaptation is between standing (1) and sitting (2) position: the patient is adjusted permanently in “a sitting position”. Sacroiliac pain is experienced in standing position

Fig. 4 Lumbosacral fusion with posterior plates and “standard” sacral position. ST = 49° in standing position (1) and 32° in sitting position (2), PT = 27° in standing position, I = 76° (“large” pelvis). Patient is pain free

Comparison of fusion patients with and without postfusion pain

Pre-operative parameters

Pre-operative PT (PTpre) was 17.3° overall, 12.4° in the subgroup without postfusion pain and 19.7° in the subgroup with postfusion pain. Corresponding values for pre-operative ST (STpre) were 41.4°, 45.7° and 39.2°. These data show that the subgroup with postfusion pain was characterized at pre-operative status by a more vertical sacrum (smaller ST value; $P = 0.0062$ using Student's *t*-test) and by a greater degree of pelvic tilt ($P = 0.0160$) (Figs. 3, 4).

Parameters at last follow-up, 2.8 years (range 1.2–6.5 years) after surgery

PT at last follow-up (PTfu) correlated with the presence of postfusion pain ($P = 0.0003$ using Student's *t*-test) (Table 4). PTfu was 22.2° overall, 13.9° in patients without postfusion pain and 26.2° in patients with postfusion pain. Thus, in the patients with postfusion pain, PT was almost twice the normal value.

ST at last follow-up (STfu) in the standing position was also correlated with the presence of postfusion pain ($P < 0.0001$) (Table 4). STfu was 36.4° overall, 43.8° in the patients without postfusion pain and 32.6° in the patients with postfusion pain. Thus, the sacrum remained abnormally vertical in the subjects with postfusion pain.

By splitting the two populations of arthrodeses into L4-S1 (54 cases) and L5-S1 (27 cases) the statistical eval-

Evaluation of nonfusion (reference) patients ($n = 24$)

In our nonfusion group, ST was 39°, PT was 18° and I was $57 \pm 11^\circ$. Overall L1-S1 lordosis was $32^\circ \pm 12^\circ$ in the sitting position and $46 \pm 11^\circ$ in the standing position (Table 2).

Global evaluation of fusion patients ($n = 81$)

Pre-operative values of ST, PT and I on standing films in the fusion group showed no statistically significant differences with the nonfusion group (Table 3). After surgery, in contrast, ST and PT in the fusion group showed significant differences versus the nonfusion group.

Radiographic abnormalities of the sacroiliac joints (sclerosis, osteophytosis or vacuum phenomenon) were seen before fusion in 11 patients and after fusion in 14 other patients; 18 of these 25 patients had postfusion pain.

Table 4 Relationships between angles and pain (detailed analysis)

	No pain (n = 27)	Pain while sitting (n = 18)	Pain while standing (n = 30)	Pain while sitting and standing (n = 6)	
STpre	45.7	43.4	38	32	$P = 0.0033$
STfu	43.8	45.2	25.8	30	$P < 0.0001$
PTpre	12.4	13.4	21.6	29.7	$P < 0.0001$
PTfu	13.9	11.7	33.9	31.6	$P < 0.0001$
Δ ST	-1.9	+1.7	-12.3	-2	$P < 0.0001$
Δ PT	+1.6	-1.6	+12.3	+2	$P < 0.0001$

uation shows the same results for L4–S1 fusions regarding ST angle, but with less significance for the L5–S1 arthrodeses no conclusion could be obtained (too few painful patients).

No correlations were found between the presence of postfusion pain and the pre-operative or last follow-up values of I, the lordosis angles, or the positions of T9, L1 or L3.

Effect of surgery-related changes in ST and PT on presence of postfusion pain

The change in PT between pre-operative status and last follow-up had a significant effect on the presence of postfusion pain ($P = 0.0213$ using Student's *t* test). The change in ST between pre-operative status and last follow-up was also significantly associated with the presence of postfusion pain (NP: $P = 0.042$). From pre-operative status to last follow-up, ST decreased by 1.9° in pain-free patients versus 6.5° in patients with pain.

Postural pain patterns

When postural pain patterns were analyzed (Table 4), patients were found to fall into two groups. Both at pre-operative status and at last follow-up, patients who were either pain free or experienced pain only in the sitting position had roughly the same pattern of pelvic tilt and sacral tilt as the nonfusion patients. Conversely, patients with pain in the standing position or in both the standing and sitting positions were characterized at pre-operative evaluation by a more vertical sacrum with a smaller degree of sacral tilt, according to the formula $I = ST + PT$.

Predictive factors for postfusion pain

We evaluated the predictive value for postfusion pain of the following parameters: STpre, STfu, PTpre, PTfu, change in ST and change in PT.

The only factor significantly associated with postfusion pain was STfu ($P < 0.0001$). Patients with the more important pre-operative variations in sacral position ac-

cording ST angles for to sitting or standing position were not especially affected by pain.

Discussion

Fusion of a spinal level is generally thought to modify the mechanical behavior of the supra- and infracent intervertebral levels, exposing them to premature degenerative disc disease [15, 22]. It has also been suggested that mechanical alterations may occur at a distance from the fused level [10, 13]. However, there are no data in the literature regarding the influence of sagittal spinal alignment on the progression of these disturbances [14]. Earlier studies have established the importance of the “normal” sagittal posture, defined as alignment on the same vertical axis of the external auditory canals, the center of the bodies of C7 and L5, the centers of the femoral heads and the center of the tibiotalar joint [20]. Sagittal alignment abnormalities may have harmful long-term effects, including degenerative disc disease at the level above spinal fusion. [22, 24, 29, 33]. Instrumentation of the lumbosacral junction can result in flatback syndrome, characterized by loss of lumbar lordosis and sagittal imbalance with anterior displacement of the weight-bearing axis, but the authors do not state the respective contributions made by loss of lordosis and pelvic retroversion. However, some patients with treatment-related loss of lumbar lordosis remain free of symptoms and there are few data in the literature on which postures are associated with pain [4, 23].

Rather than the absolute degree of lordosis [17], the relevant parameters may be the “overall” and “useful” orientation of the lumbar segments in the sagittal plane. These parameters are directly affected by the position of the pelvis.

The description by Duval-Beaupère and Robain [7] of the pelvic incidence angle and of its two components, namely pelvic tilt and sacral tilt, provide a clear understanding of the relationship between the spine and the pelvis. It is the factor that ensures balance of the trunk around the femoral heads. Pelvic tilt varies with the incidence angle of each individual and is also influenced by comorbid conditions and by surgery-related alignment changes.

Sacroiliac joint dysfunction is too often overlooked due to insufficient postural analysis [25], especially re-

garding pelvic tilt and sacral tilt. Nevertheless, the influence of gluteus maximus muscle, sacrotuberous ligament and hamstring muscles has also been proved in sacrum movements and the spine-pelvis relationship. [30]

Our study also focused on “morphologic angles” inherent in the structure of each individual (incidence angle I) and on “postural angles” amenable to modification (pelvic tilt and sacral tilt). We chose to use these angles, since this method provides better information on postural status than the junctional couple described by Vidal and Marnay [31], which neither separates the contributions of sacral and pelvic position, not takes into account constitutional anatomic variations. “Narrow” incidence angles (I) could theoretically result in limited compensation possibilities and pain (particularly sacroiliac pain), since they leave little room for angle changes to occur. Conversely, “wide” incidence angles should allow better alignment to be achieved.

None of our nonfusion or fusion patients had incidence angles below the usual range (the situation theoretically associated with limited compensation possibilities). All the subjects included in our study had normal or wide incidence angle values except 1 case with low I angle.

For our measurements, we used “full-length” radiographs in the standing position taken with the arms folded on the chest. Other investigators used radiographs taken with the arms extended on arm rests placed in front of the chest. We found in a walking platform study that this arm position was associated with substantial changes in the center of gravity.

Our overall study population (nonfusion patients and fusion patients with and without pain after surgery) was homogeneous regarding our study parameters: at pre-operative evaluation, no significant differences were found among these groups regarding I, PT or ST. These values were consistent with those reported by Duval-Beaupère and Robain [7] and by Mangione and Senegas [19].

The numerical data abstracted from each medical record confirmed that I is indeed equal to $ST + PT$. I represents the angle of “sacroiliac joint opening”, and is a morphological parameter characteristic of each individual. It is independent from the position of the pelvis and does not vary in a given individual beyond the age when walking is learned. In our study, the I angle was not significantly associated with the presence of postfusion pain.

Our analysis of follow-up PT and ST showed that patients with a more vertical sacrum (i.e., a smaller ST) and a greater PT were more likely to have postfusion pain.

A striking finding is that patients who were later found to have postfusion pain were also characterized by a pre-operatively more vertical sacrum than the nonfusion patients or the fusion patients who were pain-free at last follow-up. This result may suggest that a group of patients may be at high risk for poor functional results of lumbosacral fusion.

We maintained in our study nine patients with spondylolisthesis – seven with low fusion grade and two with

grade 3. All of them had a pelvic retroversion with a vertical sacrum. They were studied like the other arthrodeses because we think they merely represent a more caricatural mechanical and anatomical situation. Excluding those nine cases from the statistical analysis made no difference to the results.

Mangione and Senegas [19] reported that patients with degenerative lumbar kyphosis had pelvic retroversion with a normal incidence angle, indicating that the morphotype was initially normal. Loss of lordosis was associated with anterior displacement of the center of gravity and with progressive sagittal imbalance characterized by an increase in pelvic tilt and a decrease in sacral tilt (i.e., verticalization of the sacrum). These changes were partly compensated by the hips which moved to a hyperextended position, to the extent permitted by the frequent presence of hip osteoarthritis. If hip extension is limited by osteoarthritis, retroversion of the pelvis around the center of rotation of the hips becomes extreme and compensation for the imbalance occurs at the knees (knees flexion). Caution is therefore needed in patients to be fused with presurgical flexion contracture of the hips or abnormalities of the knees. We found that evaluation of the femoropelvic angle as advocated by Mangione and Senegas [19] was difficult on available radiographic documents because of the curvature of the femur and difficulties in interpreting findings near the edges of the films. In our study, flexion contracture of the hips, which was often asymmetric, could be evaluated only in a qualitative manner, a fact that probably reduced the significance of this parameter.

Our analysis of postural postfusion pain patterns demonstrated a significant difference between patients who had pain in the standing position or in “mixed position” and those who had pain only in the sitting position. Patients with postfusion pain while standing had a more vertical sacrum after the fusion procedure. The detailed analysis shows a “parasitic” verticalisation due to the operating technique and the positioning which is more apparent in patients painful in standing position (ST decreasing from 38° to 25.8°).

In patients with pain only while sitting, none of the study parameters showed significant differences compared to nonfusion patients.

There are no data in the literature for the interpretation of such postural pain patterns [17]. Studies of large lateral radiographs in the sitting position would probably provide interesting information, although preliminary work would be needed to define a reference sitting position and to evaluate individual variations.

Conclusion

Lumbosacral fusion by no means focuses only on neurologic objectives or segmental mechanical factors. Achiev-

ing a strong fusion is not the only goal. The position of the fused vertebrae is also of paramount importance. Sagittal alignment should be done with the goal of minimizing muscle work during posture maintenance.

Our study emphasizes the difficulty of achieving optimal sacral alignment under the lumbar column during lumbosacral fusion. Alignment is obtained by adjusting the position of the patient [3, 21] and of the internal fixation material. The main risk is of failing to correct or causing excessive retroversion of a vertical sacrum – a situation that is often accompanied with loss of lumbar lordosis, as occurs during aging of the spine, and that leads to a sagittal alignment replicating the sitting position. This results in pain in the standing position, because of undue stress on the sacroiliac joints and on the hips. Increased extension of the hips occurs to reduce loads through the

adjacent spinal levels and to protect the lumbopelvic complex, most notably the sacroiliac joints.

Lumbosacral morphotype and therefore the incidence angle vary across individuals. It seems preferable to horizontalize the sacrum, i.e., to increase standing ST and to decrease PT (especially in patients with preoperative abnormalities in these parameters). However, we cannot make any recommendations for avoiding the theoretical risk of predominant pain in the sitting position in patients with a markedly horizontal sacrum. Furthermore, this study does not allow us to give a precise interval for the optimal alignment of the lumbopelvic couple.

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