Radiological analysis of ankylosing spondylitis patients with severe kyphosis before and after pedicle subtraction osteotomy

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Abstract This is a radiographic study of ankylosing spondylitis patients with severe fixed kyphotic deformity who underwent pedicle subtraction osteotomy. Our goal was to measure and validate new angle to assess global kyphosis and to evaluate the radiological outcomes after surgery. This is the first report which describes new angle to assess global kyphosis (T1-S1). Pre and postoperative controls were compared according to the Pelvic Incidence. The sagittal parameters ankylosing spondylitis patients were compared with 154 asymptomatic patients. In addition to the pelvic parameters and the C7 tilt, we used the spino-sacral angle. Pelvic incidence in ankylosing spondylitis patients was higher than asymptomatic population (61 vs. 51°). For a same tilt of C7 for both groups, the low pelvic incidence group had a lower sacral slope and pelvic tilt and a higher global kyphosis (spino-sacral angle = 90°) than the high pelvic incidence group (spino-sacral angle = 98°). In the adult volunteers, the C7 tilt and spino-sacral angle measured, respectively, 95 and 135°. The preoperative C7 tilt measured 73° and increased to 83° ($p = 0.0025$). The preoperative spino-sacral angle measured 96° and increased to 113.3° ($p = 0.003$). A low pelvic incidence pelvis has a lower sacral slope than in high pelvic incidence and can support a bigger kyphosis. All the parameters were improved by the pedicle subtraction osteotomy, but the average spino-sacral angle remained lower than the control group. When C7 tilt was useful to assess the improvement of the balance, SSA allowed a better evaluation of the correction of kyphosis itself.

Keywords Kyphosis · Ankylosing spondylitis · Pedicle subtraction osteotomy · Spino-sacral angle

Introduction

Ankylosing Spondylitis (AS) is an inflammatory arthritis that primarily affects the spine and sacroiliac joints [1]. Advanced stages of the disease are characterized by a progressive stiffening of the spine and thorax. The sagittal balance of the patient deteriorates during the course of the disease, producing a rigid thoracolumbar kyphosis. A severe thoracolumbar kyphosis results in a downward tilt of the head and face [2]. The ability of the patient to see above the level of the horizontal gaze progressively worsens. The center of gravity moves anteriorly, resulting in the stooped, downward-looking posture that is characteristic of advanced AS. In an attempt to rectify this situation, the patient flexes the ankles and the knees, retroverts the pelvis positioning the hips in extension (when they seem to be clinically in flexion), and tilts the entire rigid segment of the spine backwards. This posture is usually unable to completely compensate for the thoracolumbar kyphosis. Therefore, the standing position of the patient represents the maximal posterior tilt of the pelvis, which is proved radiological by the orientation of sacral slope which may reach a complete horizontal orientation. This position is biomechanically inefficient, and painful, and the patient fatigues easily while walking or standing [3–8]. As hips are in maximal extension, there is a limited posterior gait step, increasing trunk forward imbalance when walking. The global position of the patient was evaluated by the C7 plumbline (Fig. 1); it should fall through the posterior superior corner of S1 and the hip joints. The kyphosis tilt angle (Fig. 1) is a positional parameter that is defined as

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Fig. 1 The measurement of the radiographic severity of the kyphotic deformity includes a description of the chin-brow to vertical angle; the position of the sagittal vertical axis from the external auditory canal; the C7 plumb line; and the kyphosis tilt angle

the angle between the vertical axis and a line drawn from the center of T1 to the center of the inferior kyphotic vertebral body. This angle describes the tilt induced by the global kyphosis. When the entire spine is kyphotic and L5 is the inferior vertebral body in kyphosis, the kyphosis tilt angle is equivalent to the spinal tilt angle. Both the kyphosis and spinal tilt angles are dependent upon positional changes in the lower extremities. With extension of the knees, the kyphosis tilt angle increases. With extension of the hips, retroversion of the pelvis, and flexion of the knees and ankles, the kyphosis tilt angle is reduced.

Legaye et al. [9] have described three angles that regulate spinal sagittal curves: pelvic incidence (PI), a shape pelvic parameter is the primary determinant of pelvic positioned parameters pelvic tilt (PT) and sacral slope (SS), due to the relation $PI = PT + SS$. PI is the adaptive parameter to correct worse spinal posture. The surgical management of this deformity is complicated, with controversies regarding different treatment approaches [3, 4, 10–14]. In general, the pathological posture of the spine and its correction by osteotomy has been evaluated by extrinsic parameters regarding vertical or horizontal lines. In this study a new angle is used to describe the intrinsic shape of the spine and pelvis.

The purpose of this current study was to describe new angles to assess global kyphosis regarding the pelvic shape and to evaluate the radiological outcomes of pedicle subtraction osteotomy in AS patients with severe fixed kyphotic deformity.

Materials and methods

Materials

The control group was a cohort of 154 asymptomatic young adult volunteers who were recruited mainly from the pool of medical and paramedical students at our institution. Results provided from previous published study [15].

The second group was composed of 28 consecutive AS patients with fixed kyphotic deformity who underwent pedicle subtraction osteotomy (PSO) by the senior author. There were 9 females and 19 males with a mean age of 41.7 ± 8.3 years (range 22–64).

Radiologic assessment

A similar radiologic protocol was used at both situations, with 30×90 -cm left-to-right lateral radiograph of the pelvis and entire spine obtained with each subject and patient. The distance from the radiographic source to the cassette was maintained at 230 cm for all exposures. The radiographic beam was centered with respect to the centroid of the rectangular cassette. Radiologic assessment was performed before operation and at last follow-up (minimum 2 years). In AS group knees were left in natural flexion for adaptive balance to the kyphosis. Sometimes due to the deformity, head could be outside the X-rays. But we always were able to capture T1. In control group lower limbs were always positioned with knees in full extension. In some AS patients, C7 was not visible on lateral radiographs.

Radiologic measurements included sacral slope (angle formed between the sacral endplate and the horizontal plane), pelvic tilt (angle between the vertical plane and a straight line joining the centers of the femoral heads and the center of the sacral endplate), pelvic incidence (angle between a line drawn from center of the hip axis to the center of the superior endplate of S1 and perpendicular to the endplate), kyphosis tilt angle, and two new angles (Fig. 2a). The L line was defined by the line joining the center of C7 and the center of the sacral endplate). The first was the C7 tilt (C7T) defined by the angle formed between the L line and the horizontal plane. The second was the spino-sacral angle (SSA); it was the angle between the L line and the sacral endplate. SSA was intrinsic angles of the spine and pelvis. In a rigid spine, they were considered as

Fig. 2 a The spino-sacral angle (SSA) is defined as the angle between a line from the center of C7 to the center of the sacral endplate and the sacral endplate itself. The C7 tilt (C7T) is defined by the angle formed between the line joining the center of C7 and the center of the sacral endplate and the horizontal plane. Preoperative values of SSA and C7Tilt were respectively 85 and 72°.

b Postoperative radiograph of the same patient. Transpedicular osteotomy of L4. Postoperative values of SSA and C7Tilt were respectively 96 and 85°

shape angles, when C7tilt was an extrinsic and positional angle.

Both cohorts were measured with dedicated software (Softimage Spine, Optimage, Lyon, France) on numerical X-rays. Statistical analysis was done by Wilcoxon signed ranks test and paired sample *t* test.

Operative methods

The current authors performed osteotomy at L4 in the early stage of this study (Fig. 2b). One-level osteotomy was performed in all patients. Osteotomies were performed at L3 in 12, and L4 in 16 patients. Angulations osteotomies ranged between 30 and 40°.

Results

In the young adult volunteers, the mean $\pm$ standard deviation C7 tilt, SSA, and kyphosis tilt angle (KTA) measured, respectively, 95.4 ± 1.4 , 135.2 ± 3.8 , and $93.4 \pm 2.4^\circ$.

In AS patients with fixed kyphotic deformity who underwent pedicle subtraction osteotomy the changes of various angles figure in Table 1. The mean preoperative C7 tilt measured $72.6 \pm 14.7^\circ$ and increased to $83.1 \pm 7.3^\circ$ at the final follow-up ($p = 0.0025$). The mean preoperative SSA measured $96.4 \pm 17.8^\circ$ and increased to $113.3 \pm 11.6^\circ$ at the final follow-up ($p = 0.003$). The mean preoperative KTA measured $74.9 \pm 12.7^\circ$ and increased to $85.3 \pm 6.3^\circ$ at the final follow-up ($p = 0.003$).

Table 1 Radiologic assessment of the control group and of the AS patients before and after surgery

	Young adult volunteers	Preoperative	Postoperative	<i>p</i> value
PI ($^\circ$)	50.6 ± 5.2 (32–82)	61.9 ± 13.7 (36–88)	61.5 ± 11.3 (40–90)	NS
SS ($^\circ$)	39.5 ± 7.6 (16–55)	23.9 ± 11.3 (0–45)	30.2 ± 9.8 (12–50)	0.003
PT ($^\circ$)	11.1 ± 5.8 (8–34)	38.5 ± 10.9 (15–64)	31.7 ± 9.2 (13–50)	0.003
C7T ($^\circ$)	95.4 ± 1.4 (90–97)	72.6 ± 14.7 (23–98)	83.1 ± 7.3 (60–95)	0.0025
SSA ($^\circ$)	135.2 ± 3.8 (129–138)	96.4 ± 17.8 (48–128)	113.3 ± 11.6 (94–135)	0.003
KTA ($^\circ$)	93.4 ± 2.4 (88–100)	74.9 ± 12.7 (29–93)	85.3 ± 6.3 (64–96)	0.003

PI pelvic incidence, SS sacral slope, PT pelvic tilt, C7T C7 tilt, SSA spino-sacral angle, NS no significative, KTA kyphosis tilt angle

Table 2 Radiologic assessment of the AS patients with low PI ($\leq 50^\circ$)

N = 7	Preoperative	Postoperative	p value
PI ($^\circ$)	45.6 $\pm$ 5.2 (36–50)	47.1 $\pm$ 5.8 (38–50)	NS
SS ($^\circ$)	13 $\pm$ 9.4 (0–28)	22.1 $\pm$ 7.5 (12–32)	0.002
PT ($^\circ$)	32.7 $\pm$ 8.4 (22–47)	26.1 $\pm$ 7.8 (15–38)	0.003
C7T ($^\circ$)	72.3 $\pm$ 6.7 (66–88)	86.4 $\pm$ 5.7 (77–95)	0.0025
SSA ($^\circ$)	90.3 $\pm$ 7.6 (80–100)	108.6 $\pm$ 9.5 (98–120)	0.003
KTA ($^\circ$)	74.3 $\pm$ 7.7 (65–90)	81.4 $\pm$ 6.7 (74–97)	0.003

Table 3 Radiologic assessment of the AS patients with high PI ($> 50^\circ$)

N = 21	Preoperative	Postoperative	p value
PI ($^\circ$)	67.3 $\pm$ 10.7 (52–88)	65.9 $\pm$ 8.3 (53–90)	NS
SS ($^\circ$)	27.5 $\pm$ 9.3 (13–45)	33 $\pm$ 8.9 (20–50)	0.003
PT ($^\circ$)	40.4 $\pm$ 10.8 (15–64)	33.6 $\pm$ 8.8 (13–50)	0.003
C7T ($^\circ$)	71 $\pm$ 15.9 (23–98)	82 $\pm$ 7.4 (60–92)	0.0025
SSA ($^\circ$)	98.5 $\pm$ 19.4 (94–135)	115 $\pm$ 11.8 (94–135)	0.003
KTA ($^\circ$)	70 $\pm$ 13.9 (25–96)	80 $\pm$ 6.4 (64–93)	0.003

The pelvic incidence (PI) measured $50.6 \pm 5.2^\circ$ in the control group and 61.9 ± 13.7 in SA group. The patients with a low PI ($PI \leq 50^\circ$, $n = 7$) had a lower preoperative SSA compared to the patients with a high PI ($PI > 50^\circ$, $n = 21$). The preoperative C7 tilts were similar in these both groups. The radiological details of the AS patients concerning the function of the PI were incorporated into Tables 2 and 3.

Discussion

Radiological assessment

Several authors have demonstrated that the radiographic appearance of kyphosis is dependant upon the position of the lower extremities [5, 6]. It is not possible to measure the position of the lower extremities on the same lateral radiograph as the spine and pelvis. Therefore, it is important to describe the relationship between the pelvis and the spine in a way that is independent of the position of the hips, knees, and ankles. The spino-pelvic angle (SSA) is defined as the angle between a line from the center of C7 to the center of the sacral endplate and a line from the center of the sacral endplate to the center of the hip axis. In the presence of a kyphotic deformity, the angle decreases significantly. The spino-sacral angle (SSA) is defined as the angle between a line from the center of C7 to the center of the sacral endplate and the sacral endplate itself. SSA is correlated at the kyphosis. It may be useful in the strategy

correction. In our series PI is significantly increased compared to our control group. All our patients were operated for severe kyphosis. Two explanations are possible: either that the high PI patients are less able to compensate, or that a flat back with a low PI is less able to develop a severe kyphosis by the way of the disease (flat remains flat, high lordosis may decrease).

Adaptation of the sagittal balance in evolution of a kyphotic deformity

The stages of adaptation to a significant kyphosis with anterior displacement of the center of gravity proceeds as follows: in order to maintain C7/T1 over the endplate of the sacrum, pelvic tilt is first increased by extension of the hips, and once the pelvic tilt reaches the maximum, the knees are flexed in order to tilt the rigid spine and pelvis posteriorly.

When the patient tilts the pelvis posteriorly, the sacral end offset regarding femoral heads increases. On a geometrical point of view, as the sum of the sacral slope and the pelvic tilt is equal to pelvic incidence, the ability of the spine to compensate for the deformity is limited by the patient's native anatomic alignment. A patient with a large pelvic incidence is able to compensate for a kyphotic deformity by inducing a large posterior tilt to the pelvis, until reaching a flat sacral endplate, which increases the sacral end offset. However, a patient with a very low pelvic incidence does not have the same capacity to accommodate the deformity. In others terms, with a same quantity of kyphosis (C7tilt), a patient with a high pelvic incidence will have a higher SSA than a patient with a low pelvic incidence.

Theoretically, a patient with a low PI would be less able to compensate a severe kyphosis than one with high PI. As the maximum retroversion provided by a low PI pelvis is inferior to a high PI, SS trends to 0° . In our study we do not confirm this evidence. SSA is bigger in low PI patients than in high PI. Otherwise, the average SS is closer to horizontal in low PI than in high PI. According to C7 position the level of imbalance is the same in all cases. It seems that in low PI it is easier to reach a 0° of SS than in high PI. This is probably due to the limitation of hip extension which forbids the pelvis to reach a too high level of retroversion.

Effect of lumbar osteotomy for kyphosis correction

The severity of the kyphosis and the results of surgical treatment are well assessed by the spino-sacral angle (SSA) which may be considered as an evaluation of the whole kyphosis of both thoracic and lumbar areas. The comparison with the asymptomatic population shows that the SSA is lower than 39° in the ankylosing spondylitis patients.

After surgical treatment, it is improved by only 17° . As kyphosis is not corrected enough, they are still compensation in pelvic position (increasing retroversion). The sagittal balance is not sufficiently corrected with a low sacral slope (30°) and a high pelvic tilt (31°). The position of C7 characterized by the C7 tilt was largely anterior before surgery (72° for a normal at 95°) and better positioned after (83°).

The goals of surgical correction of sagittal malalignment in ankylosing spondylitis are to decrease the cosmetic and functional effects of the deformity, reduce the patient's pain, and increase their ability to stand and walk comfortably [4, 7, 16, 17]. A number of techniques for inducing a posterior tilt to the spine and returning the gaze to the horizontal have been described [3, 11, 17–20]. These techniques include an opening wedge anterior osteotomy, vertebral body corporectomy and realignment, multiple posterior wedge osteotomies of the posterior elements only, and osteotomy of the anterior and posterior column or pedicle subtraction technique.

In the process of preoperative planning, it is important to determine both how much correction is desirable, and how much correction is achievable. In the published results with pedicle subtraction, single-level corrections of more than 40° are rare [4, 17]. If more than 40° of corrections are desirable, then multiple closing wedges of the spine are likely to be necessary.

The amount of correction that is needed to place the center of C7 vertebral body directly above the sacral endplate with the patient's knees in extension is determined by the amount of kyphosis and the alignment of the spine and pelvis. Our results demonstrate that in both groups, high and low PI, preoperative C7 tilt was similar after surgery; there were a better position of C7 in low PI group. The global balance was better in the low PI group ever with a worse SSA initial angle. Our results suggested that with only one level of PSO, the ideal balance was not achieved (SSA close to 135° , pelvis tilt around 20°) in all our patients and worse in those with a high-grade PI. It was very important to obtain the best sagittal balance after surgery because the insufficient correction of a sagittal deformity might lead to recurrence of deformity in the long term with the reappearance of the symptoms [3–7].

In summary, there is an important difference between balances of severe kyphosis regarding the value of Pelvic Incidence. In case of low pelvic Incidence, SSA has to be higher than in a system with a high PI to position C7 with a same plumb line with regard to the pelvis. In other words, to have the same C7 plumb line position, there is more kyphosis deformity with High PI pelvis than with low PI pelvis (Fig. 3). The strategy of correction has to take in account both the repositioning of C7 plumb line and the reduction of the pelvic tilt. We propose a geometrical

Fig. 3 For the same preoperative C7 plumb line, the patients with a high PI have a lower SSA (*left*) than those with a low PI (*right*)

sequence of calculation of the quantity of SPO using the correction of SSA. The first step is to rotate the whole set of spine and pelvis around the femoral head axis in order to bring the sacral end with an average ideal Pelvis Tilt of 20° . Then in a second step we virtually bring C7 over the pelvis. This maneuver provides the quantity of correction of SSA necessary to perform an ideal osteotomy. Evidently this strategy is useful only in case of rigidity of the whole spine like in SA diseases. It is evident on Fig. 4a, b that the correction of a same unbalanced C7 plumb line needs a smaller osteotomy in case of low-grade incidence than with a high Pelvic Incidence. The strategy of correction of severe kyphosis has to take in account the level of pelvic incidence to appreciate the quantity of the osteotomy.

Conclusion

Pedicle subtraction osteotomy in ankylosing spondylitis patients with severe fixed kyphotic deformity was safe and could obtain large amount of correction with a single-level osteotomy. Postoperatively, all the parameters were improved by the PSO but the average SSA remained lower than the control group mainly when there was a high-grade pelvic incidence. SSA is a good indicator to assess the whole deformity of the spine in severe kyphosis. Its insufficient correction by a PSO alone explains the

Fig. 4 a, b Correlation between the quantity of the osteotomy and the level of pelvic incidence. We base our preoperative plan upon a radiograph of the entire spine between the occiput and the proximal femurs. It is not necessary to calculate the osteotomy based upon a radiograph taken with the patient's knees in full extension because the rigid fused spine and pelvis provides sufficient information. Using the spino-sacral angle (SSA), we calculate the amount of correction required to place the center of T1 directly over the sacral endplate (A). If the desired amount of correction is $<45^\circ$, we feel that this can be achieved with a single-level posteriorly based pedicle subtraction osteotomy in the lumbar spine. The correction of a same unbalanced C7 plumb line (C7 P) needs a smaller osteotomy in case of low grade incidence than with a high pelvic incidence. The strategy of correction of severe kyphosis has to take in account the level of pelvic incidence to appreciate the quantity of the osteotomy

remaining retroverted pelvis after correction. When C7 tilt was useful to assess the improvement of the balance, SSA allowed a better evaluation of the correction of kyphosis itself. We must emphasize the role of the pelvic incidence in balancing severe kyphosis and in strategy of correction by PSO.

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