Sagittal alignment of the cervical spine in adolescent idiopathic scoliosis treated by posteromedial translation

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Received: 26 May 2012/Revised: 6 August 2012/Accepted: 24 August 2012/Published online: 11 September 2012
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Abstract

Purpose To analyze postoperative changes in the cervical sagittal alignment (CSA) of patients with AIS treated by posteromedial translation.

Methods 49 patients with thoracic AIS underwent posterior arthrodesis with hybrid constructs, combining lumbar pedicle screws and thoracic universal clamps. Posteromedial translation was the main correction technique used. 3D radiological parameters were measured from low-dose biplanar radiographs. CSA was assessed using the C2C6 angle, and the central hip vertical axis (CHVA) was used as a reference axis to evaluate patients' balance.

Results Preoperatively, 58 % of patients had thoracic hypokyphosis, and 79 % had a kyphotic CSA. Significant correlation was found ($r = 0.45$, $P = 0.01$) between thoracic hypokyphosis and cervical kyphosis. Increase in T4–T12 thoracic kyphosis (average $14.5^\circ \pm 10^\circ$) was associated with significant decrease in cervical kyphosis in the early postoperative period. The CSA further improved spontaneously during follow-up by 7.6° ($P < 0.0001$). Significant positive correlation ($r = 0.32$, $P = 0.03$) was found between thoracic and cervical improvements. At latest follow-up, 94 % of the patients were normokyphotic and 67 % had a CSA in the physiological range. Sagittal balance of the thoracolumbar spine was not significantly modified postoperatively. However, the

procedure significantly changed the position of C2 in regard to the CHVA (C2–CHVA), which reflects headposition ($P = 0.012$). At last follow-up, the patients sagittal imbalance was not significantly different from the preoperative imbalance ($P = 0.34$).

Conclusions Thoracic hypokyphosis and cervical hypolordosis, observed in AIS, can be improved postoperatively, when the posteromedial translation technique is used for correction. The cervical spine remains adaptable in most patients, but the proportion of patients with physiological cervical lordosis at final follow-up remained low (24.5 %).

Keywords Adolescent idiopathic scoliosis · Cervical · Sagittal · Hybrid constructs · Universal clamp · Posteromedial translation

Introduction

Scoliosis is a three-dimensional (3D) spinal deformity, which usually includes a loss of thoracic kyphosis and lumbar lordosis. While the primary goal in adolescent idiopathic scoliosis (AIS) surgery is to correct frontal deformities, an additional major challenge is to restore or preserve a physiological sagittal profile to limit long-term functional impairment due to degenerative changes adjacent to the fused vertebrae [1–7]. Whereas the unfused spine distal to scoliosis instrumentation has been widely studied, few reports have evaluated postoperative changes in cervical sagittal alignment (CSA) [2, 4, 8], which could be clinically relevant since the incidence of cervical complaints is high, ranging from 17 to 57 %, which have been reported after scoliosis fusion [8, 9]. In addition, correlations have been reported between cervical kyphosis and

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axial neck pain in posttraumatic and degenerative conditions [4, 10, 11].

Flattening or kyphosis of the cervical spine has already been reported in patients who have thoracic hypokyphosis after fusion for scoliosis with Harrington rods [8]. Recently, Imrie et al. [12] emphasized that the development and application of powerful pedicle screw-aided instrumentation constructs had sometimes led to excellent coronal correction, but at the expense of sagittal alignment. The difficulty of restoring physiological thoracic kyphosis in AIS patients treated by selective posterior thoracic fusion with all-pedicle screw constructs and direct vertebral derotation has also been reported [13, 14]. Hybrid constructs, using sublaminar bands and posteromedial translation as correction technique, have been shown to preserve or restore physiological thoracic kyphosis, but their effect on the cervical spine has never been assessed [15, 16]. The purpose of the present study was to analyze postoperative changes in the CSA of patients with AIS treated by posteromedial translation.

Materials and methods

Patients

Following institutional review board approval, 49 consecutive patients operated for AIS (Lenke 1–4) were prospectively included. A minimum of 2-year follow-up was required. All patients were evaluated preoperatively, in the early postoperative period (within 3 months), and at last follow-up. None of the patients had prior spinal surgery.

Operative procedure

All patients underwent posterior spinal fusion and instrumentation using hybrid constructs, combining lumbar Java pedicle screws (Zimmer Spine, Bordeaux, France) and Universal Clamps (UC) (Zimmer Spine, Bordeaux, France) at thoracic levels. Fusion levels were selected following the same criteria during the entire study period, and 5.5 titanium alloy rods were used in all cases [15, 17]. The proximal fusion level was located between T2 and T4 in all cases, and no selective fusion was performed. Universal Clamps were used at all levels (1 per level) in the thoracic concavity, and 2 UC (1 in the concavity and 1 in the convexity) were placed on the apical vertebra. The two rods were precontoured in the sagittal plane and connected with two transverse connectors. The rods were first introduced in the pedicle screws, and the lumbar correction was performed. Posteromedial translation was the main technique used for thoracic correction (Fig. 1), as previously described, while in situ contouring, compression and/or

distraction were added to level both the proximal and the distal instrumented levels [16]. No patient underwent prior anterior release before the posterior fusion. During the procedures, spinal cord function was monitored by means of somatosensory/motor-evoked potentials.

Biplanar radiographic system

Low-dose biplanar radiographs (EOS imaging, Paris, France) were obtained preoperatively, postoperatively and at latest follow-up within routine clinical procedures [18]. The EOS system is a slot-scanning radiologic device consisting of two X-ray sources, allowing simultaneous acquisition of two images and 3D measurements [19]. The sources are coupled to linear detectors that are based upon micromesh gaseous structure technology [20]. The two source-detector pairs are positioned orthogonally, so the patient's anteroposterior and lateral images are generated line-by-line while the whole system is vertically translated. Patients were in weight-bearing position, arms folded at 45° in order to avoid superposition with the spine. All images included the base of the skull and the upper third of the femurs. Scan time lasted from 8 to 15 s for a spine examination, depending on the patient's height.

Radiological parameters

In accordance with previous studies, the CSA was assessed by measuring the angle between the lower endplate of C2 to the lower endplate of C6 [21, 22]. Canavese et al. [21] have reported the excellent inter-observer reliability of this angle. C6 was chosen as the distal endpoint for total CSA because this vertebra could be adequately visualized for all patients [21]. This angle was considered to be negative in patients with cervicallordosis, and positive in those with cervical kyphosis. Cervical lordosis between -20°

Fig. 1 Axial view of the schematic pathway of the vertebrae during posteromedial translation

and -40° was considered as normal [23, 24]. In addition, the following radiological parameters of sagittal spinopelvic alignment were measured: T4/T12 kyphosis, L1/S1 lordosis, and pelvic incidence [25].

As recommended by the Scoliosis Research Society 3D committee, the central hip vertical axis (CHVA) was used as the reference axis to evaluate patients' balance [26]. Global sagittal alignment was determined by measuring the distances between the center of T1 and the CHVA (T1–CHVA), and between the posterior inferior corner of C2 and the CHVA (C2–CHVA) (positive value in case of anterior shift).

Statistical analysis

Two-tail paired *t* tests were used to compare preoperative and postoperative measurements. Pearson tests were used to analyze the correlation between thoracic kyphosis and cervical lordosis. A *P* value of <0.05 was considered to be significant. All statistical analyses were conducted using the software Statview (SAS Institute Inc, Cary, NC, USA).

Results

Demographic data and operative procedures

There were 45 girls and 4 boys (average age 15 years, range 13–17), with a Cobb angle averaging $61.2^\circ \pm 13^\circ$ (45° – 92°). Mean follow-up was 32 ± 6 months (25–42 months). The mean number of levels fused was 13.5 ± 1 (range 11–15). The number of Universal Clamps (UC) used for thoracic correction averaged 6.8 (range 5–10). The apical vertebra was instrumented with two UCs in all cases. The average operative time was 215 ± 25 min. No intraoperative complication was reported. In particular, no significant change in the monitored somatosensory/motor-evoked potentials was recorded during insertion of the sublaminar bands.

CSA and thoracic kyphosis

Measurements of cervical lordosis and thoracic kyphosis are reported in Table 1. Preoperatively, 58 % of the patients had thoracic hypokyphosis ($<20^\circ$), and 79 % of the cohort had a kyphotic CSA. A significant correlation was found ($r = 0.45$, $P = 0.01$) between preoperative thoracic kyphosis and cervical lordosis.

Thoracic kyphosis was significantly increased postoperatively, with a mean T4–T12 gain of $14.5^\circ \pm 10^\circ$ in the overall population, and $18.8^\circ \pm 9^\circ$ in the subgroup of hypokyphotic patients. This increase in thoracic alignment was associated with a significant decrease in cervical kyphosis in the early postoperative period.

Table 1 Postoperative modifications of the sagittal thoracic and cervical parameters

	Preop	Postop	Follow-up
T4–T12 kyphosis (mean $\pm$ SD)	$18^\circ \pm 13^\circ$	$30.2^\circ \pm 7^\circ$ $P = 1.2\text{E}-6$	$32.4^\circ \pm 9^\circ$ $P = 1.5\text{E}-12$
C2–C6 angle (mean $\pm$ SD)	$11.2^\circ \pm 15^\circ$	$0.3^\circ \pm 12^\circ$ $P = 6.7\text{E}-7$	$-7.5^\circ \pm 12^\circ$ $P = 1.1\text{E}-16$

SD standard deviation, *P* comparison with preoperative values

No significant modification in thoracic kyphosis was observed during follow-up, but the CSA further improved spontaneously, with a mean gain of lordosis of 7.6° ($P < 0.0001$) (Fig. 2). None of the patients developed a secondary loss of cervical lordosis after initial correction.

C2–C6 kyphosis decrease averaged $18.8^\circ \pm 10^\circ$. However, C2–C6 angles remained lower than normal values, with only 12 patients (24.5 %) having a cervical lordosis $>20^\circ$ (Fig. 3). A significant positive correlation ($r = 0.32$, $P = 0.03$) was found in the cohort between thoracic and cervical sagittal improvements. This correlation was even stronger in the subgroup of hypokyphotic patients ($r = 0.48$, $P = 0.009$). At latest follow-up, 94 % of the patients had normal thoracic kyphosis and 67 % had a CSA between -20° and -40° .

Lumbar and pelvic sagittal alignment

Table 2 summarizes the postoperative changes of the lumbopelvic sagittal parameters. Pelvic incidence and lumbar lordosis were not significantly modified postoperatively.

Global sagittal balance

Global sagittal balance parameters are reported in Table 3. Preoperatively, 90 % of the patients were posteriorly balanced in terms of the T1–CHVA, and the sagittal balance of the thoracolumbar spine was not significantly modified after correction of the deformity (average 6.3 ± 21 mm). However, the procedure did significantly change the average value of C2–CHVA, which reflects the position of the head. The average C2–CHVA increased from -12 mm preoperatively to 1 mm postoperatively ($P = 0.012$), but at last follow-up, the patients sagittal imbalance was not significantly different from the preoperative imbalance, with a final average C2–CHVA of -8 mm ($P = 0.34$).

Discussion

Preoperative CSA

Interest in the sagittal alignment of the thoracolumbar spine and pelvis in patients with AIS is growing [3, 5, 13, 14, 27,

Fig. 2 Preoperative, early postoperative and latest follow-up lateral radiographs of a 16-year-old girl with thoracic AIS, showing the progressive improvement in CSA

28]. Abnormal spinopelvic balance and pelvic morphology with flattened sagittal contours are common in AIS. Most studies of lumbar lordosis and thoracic kyphosis have failed to include the cervical column in their analysis, but some authors have already reported an associated loss of cervical lordosis [9, 10, 22]. In 1995, Hilibrand et al. published a radiographic study of the sagittal alignment of the cervical spine in AIS patients, and found that 89 % of the patients had a straightened or kyphotic CSA. They also noted an inverse correlation between the thoracic and the cervical alignment [22]. This correlation was confirmed by Loder et al. [29], in a series of 30 patients with Arnold-Chiari I malformation with associated scoliosis. Results of the current study confirm the previous findings, with 79 % of the cohort having a kyphotic CSA preoperatively. In addition, the flattening of the CSA was correlated with thoracic hypokyphosis ($r = 0.45$), at a rate (58 %) higher than in previous reports.

Postoperative modification of the cervical spine

One of the goals in AIS surgery is to restore an optimal sagittal alignment, to reduce the incidence of adjacent segment degeneration and junctional malalignment [4, 5, 30, 31]. The relationships among postoperative thoracic, lumbar and pelvic sagittal parameters have been extensively characterized, with most studies demonstrating the difficulty in correcting both scoliosis in the frontal plane and in the thoracic hypokyphosis with hooks or all-pedicle screw constructs [3, 12–15, 28]. Reports on postoperative changes in the cervical spine remain scarce [4, 21, 22]. Hilibrand et al. were the first to precisely measure the postoperative modification of the CSA, using the C2–C6 angle, and concluded that Cotrel-Dubousset and Harrington instrumentations failed to correct the preoperative cervical kyphosis [22]. In a series of 32 AIS patients operated with multisegmented hook and screw instrumentation, Canavese

Fig. 3 Preoperative and latest follow-up lateral radiographs of a 15-year-old girl, showing improvement of the CSA. However, the C2–C6 angle remained kyphotic and under physiological values

Table 2 Postoperative modifications of the sagittal lumbar and pelvic parameters

	Preop	Postop	Follow-up
L1S1 lordosis (mean $\pm$ SD)	53.7° $\pm$ 14°	54.3° $\pm$ 10° $P = 0.9$	56° $\pm$ 12° $P = 0.12$
Pelvic incidence (mean $\pm$ SD)	54.3° $\pm$ 14°	54.1° $\pm$ 13° $P = 0.47$	54° $\pm$ 12° $P = 0.81$

SD standard deviation, P comparison with preoperative values

Table 3 Postoperative modifications of the global sagittal balance parameters

	Preop	Postop	Follow-up
T1–CHVA (mean $\pm$ SD)	–27.7 mm $\pm$ 25	–32.2 mm $\pm$ 18 $P = 0.09$	–34 mm $\pm$ 21 $P = 0.07$
C2–CHVA (mean $\pm$ SD)	–12 mm $\pm$ 26	1 mm $\pm$ 21 $P = 0.012$	–8 mm $\pm$ 20 $P = 0.34$

SD standard deviation, CHVA central hip vertical axis, P comparison with preoperative values

et al. [21] also concluded that the inherent rigidity of the cervical spine limited changes in sagittal alignment. However, only 21.9 % of their subjects were hypokyphotic preoperatively, and the gain in thoracic kyphosis averaged

1.9°. This low increase in thoracic kyphosis due to the scoliosis correction technique might explain the lack of improvement observed in the cervical spine. The population of our study was comparable regarding the frontal

Fig. 4 Preoperative and latest follow-up lateral radiographs of a 15-year-old girl with thoracic AIS. The present posteromedial translation technique with sublaminar bands significantly improved the thoracic hypokyphosis, and was associated with a substantial cervical sagittal improvement

deformity (61.2° vs. 57.8°), but presented with a more altered sagittal alignment (58 % hypokyphotic patients). The present posteromedial translation technique with sublaminar bands significantly improved the thoracic sagittal contour, and was associated with a substantial cervical sagittal improvement, particularly visible by EOS stereoradiography in the hypokyphotic subgroup ($r = 0.48$, $P = 0.009$) (Fig. 4). Cervical lordosis increased by an average of 11° in the early postoperative period, and the CSA continued to improve during follow-up (7.6°). The result was a lordotic CSA in 67 % of the patients at latest examination. To our knowledge, this spontaneous favorable course of cervical alignment after the early postoperative period has never been reported previously.

Inclusion of the cervical spine in global sagittal balance

Low-dose biplanar radiographs provided 3D reconstructions that were used to evaluate balance [18, 25]. The present results reveal the usefulness of extending an

analysis of surgical results proximally at least enough to include the cervical spine. Indeed, an evaluation based upon a conventional criterion, e.g., the distance between T1 and the CHVA, would have falsely concluded in the absence of effect of surgery upon the global sagittal balance. The ultimate goal of sagittal balance is to position the head vertical to the pelvis and obtain a horizontal gaze. Consequently, including the cervical spine, using C2–CHVA findings, provides more information on the compensatory mechanisms involved. In the present series, the measurement of the C2–CHVA distance showed that the lumbar lordosis was not affected postoperatively, even though a physiological thoracic kyphosis was restored. This situation led to an anterior shift of the head, probably due to stiffness of the cervical spine in a position of kyphosis or hypolordosis. In contrast to the conclusions of Canavese et al. [21], our results show that adolescents have the potential to adapt over time, recovering some cervical lordosis and thereby returning to their initial balanced position.

Limitations of the study

There are several weaknesses in this study. The follow-up period was short (34 months), but it is now accepted that loss of correction after fusion in AIS primarily occurs during the first postoperative year and that results of spine surgery can be reliably evaluated radiologically after a minimum follow-up of 2 years [32]. Because the sample size was small and no control group was used, further investigations remain necessary to confirm that the postoperative change observed in the CSA was effectively caused by the posteromedial translation technique used for correction. The quantitative results were obtained using the 3D measurement tool of the IdefX software (version 4.8.4), but the development of this software and reconstruction methods will probably soon provide quicker semi-automatic models of individual subjects from C2 to the pelvis, providing more quantitative information on the cervical spine. In addition, the reproducibility of cervical measurements was not assessed in the current study. Ideally, the analysis should have been extended proximally to include the external auditory canals, which are readily visible on EOS stereoradiography if the window of image acquisition is sufficiently extended. Because the external auditory canals were included on the images of only 30 % of our subjects, we had to use C2 as the proximal cut-off. Finally, this study was only radiological and no functional score was used to evaluate patient outcomes. In particular, the correlation between the flattening of the CSA and axial pain, controversial in the literature, needs to be further explored. Cochran et al. [10] found an incidence of neck pain no greater than in the normal population in patients 5–12 years after fusion using Harrington rods. In contrast, Moskowitz et al. [9] pointed out the high incidence of cervical complaints (57 %) at long-term follow-up (20–32 years), and Edgar and Mehta [2] later confirmed an increased incidence of cervicodorsal pain in fused patients, compared to unfused ones (17.6 vs. 7.8 %). The influence of pain and muscle spasm on early postoperative CSA, as suggested by Helliwell et al. [33], also requires further investigation. In addition, the outcomes of patients with proximal junctional kyphosis need to be evaluated at long-term follow-up.

In conclusion, results of this study show that flattening of the thoracic and cervical curvatures observed in AIS can be improved postoperatively, when the posteromedial translation technique is used for correction. The cervical spine remains adaptable in most of the patients, but the proportion of patients with physiological cervical lordosis at final follow-up remained lower than that of patients with physiological thoracic kyphosis (24.5 vs. 94 %, respectively).

Conflict of interest None.

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