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Long-term three-dimensional changes of the spine after posterior spinal instrumentation and fusion in adolescent idiopathic scoliosis*

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Abstract This is a prospective study comparing the short- and long-term three-dimensional (3D) changes in shape, length and balance of the spine after spinal instrumentation and fusion in a group of adolescents with idiopathic scoliosis. The objective of the study was to evaluate the stability over time of the postoperative changes of the spine after instrumentation with multi rod, hook and screw instrumentation systems. Thirty adolescents (average age: 14.5 ± 1.6 years) undergoing surgery by a posterior approach had computerized 3D reconstructions of the spine done at an average of 3 days preoperatively (stage I), and 2 months (stage II) and 2,5 years (stage III) after surgery, using a digital multi-planar radiographic technique. Stages I, II and III were compared using various geometrical parameters of spinal length, curve severity, and orientation. Significant improvement of curve magnitude between stages I and II was documented in the frontal plane for thoracic and lumbar curves, as well as in the orientation of the plane of maximum deformity, which was significantly shifted towards the sagittal plane in thoracic curves. However, there was a significant loss of this correction between stages II and III. Slight changes were noted in apical vertebral rotation, in thoracic kyphosis and in lumbar lordosis. Spinal length and height were significantly increased at stage II, but at long-term follow-up spinal length continued to increase while spinal height remained similar. These results indicate that although a significant 3D correction can be obtained after posterior instrumentation and fusion, a significant loss of correction and an increase in spinal length occur in the years following surgery, suggesting that a crankshaft phenomenon may be an important factor altering the long-term 3D correction after posterior instrumentation of the spine for idiopathic scoliosis.

Key words Adolescent idiopathic scoliosis · Spinal instrumentation · Spine length · 3D correction

Introduction

The goals of surgical treatment in adolescent idiopathic scoliosis are correction and stabilisation of the deformity in three dimensions [9, 18], with preservation of maximum lumbar spine mobility [18]. The introduction of Cotrel-Dubousset instrumentation during the past decade has paved the way to a new generation of multi rod, hook, and screw systems, allowing the surgeon to gain for the first time adequate correction of the spine in the three planes in space [9, 15, 17, 18]. Little is known about the long-term changes in spinal shape and length after surgery. Spinal imbalance in the frontal plane has been noted after instrumentation of King type II and IV curves [21, 26], according to the level of fusion [8, 20, 26] and to the changes in the unfused levels [25, 26]. A crankshaft phenomenon [13], with continued growth of the anterior spine after posterior spinal instrumentation, is now a well-recognized syndrome in infantile and juvenile idiopathic scoliosis, but its occurrence in adolescent idiopathic scoliosis is still debated [13].

The purpose of this study was to evaluate the stability over time of the changes in shape, orientation, and length of the spine after posterior instrumentation and fusion with multi rod, hook, and screw systems, in order to determine whether changes in spinal length can alter the immediate postoperative correction obtained in adolescent idiopathic scoliosis.

Materials and methods

Thirty adolescent females with an average age of 14.5 ± 1.6 years at the time of surgery participated in the study. Twenty-four of these patients were post menarche. They were recruited at our scoliosis clinic over a 3-year period (from 1991 to 1994) and were selected according to the following criteria: (1) presence of adolescent idiopathic scoliosis, (2) indication for surgical correction as determined by an experienced orthopedic surgeon, and (3) a thoracic or lumbar curve pattern. There were 16 subjects with double curves (six King type I and ten King type II) and 14 with single curves (six thoracic King type III, five thoracic King type IV and three lumbar curves), making a total of 27 thoracic and 19 lumbar curves.

For each patient, a first 3D reconstruction of the spine was obtained preoperatively upon admission to the hospital (stage I: 3 ± 3 days before surgery). Standard 3D instrumentation with a multi rod, hook, and screw instrumentation system as well as bone grafting was performed by one of the three participating orthopedic surgeons with a similar experience of more than 10 years in spinal surgery. Derotation maneuvers were performed as described by Cotrel and Dubousset [9]. Cotrel-Dubousset instrumentation was used in 26 patients, while the Colorado system was used in two patients and the TSRH (Texas Scottish Rite Hospital) system in two others. Each subject was revaluated at 1.9 ± 1.4 months postoperatively (stage II), at which time a second 3D reconstruction of the spine was done. Finally, a follow-up visit and third 3D reconstruction at 2.5 ± 0.5 years after surgery (stage III) were also done for each patient. The 3D reconstructions were obtained from a multiplanar radiographic technique, which has been detailed in previous publications [4, 6, 10] and will only be summarized. For each reconstruction, two digital radiographs of the spine were done in the standing position, inside a positioning apparatus that standardizes the position of the patient. This apparatus incorporates a calibration object made of two acrylic sheets mounted at the front and back, in which are embedded 50 steel balls, 2 mm in diameter, whose 3D coordinates are known with high precision for calibration

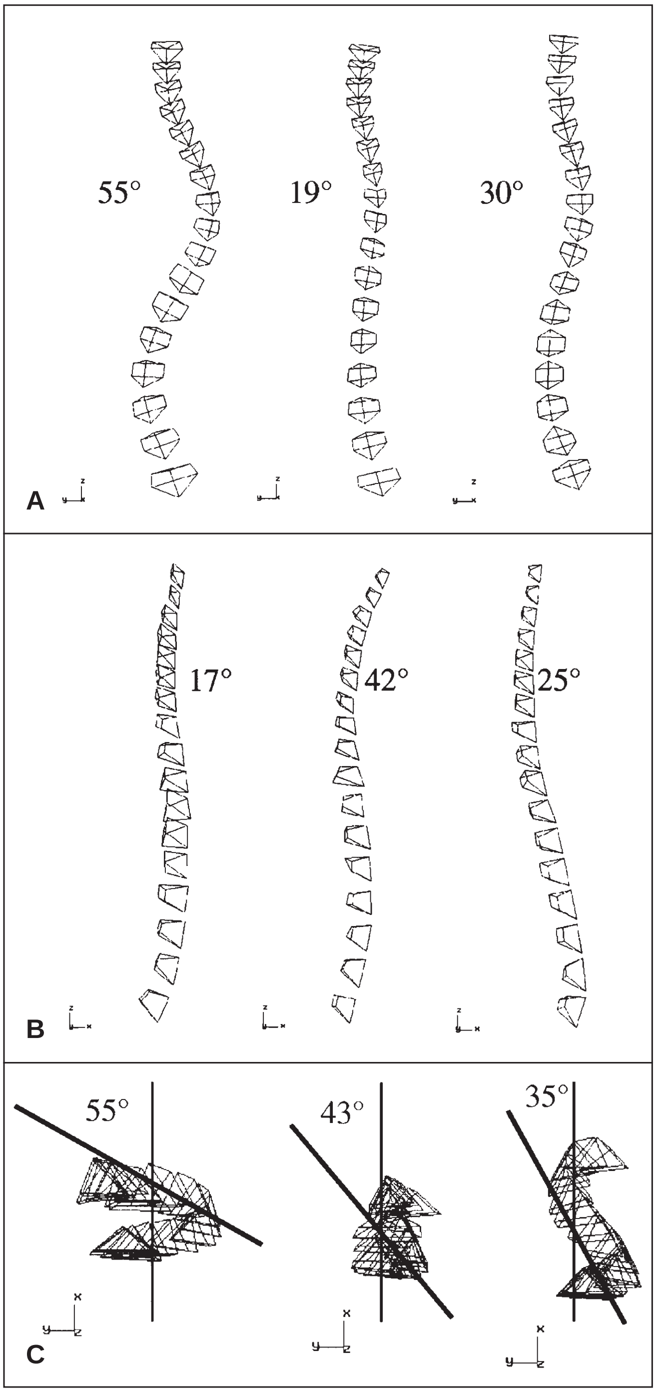
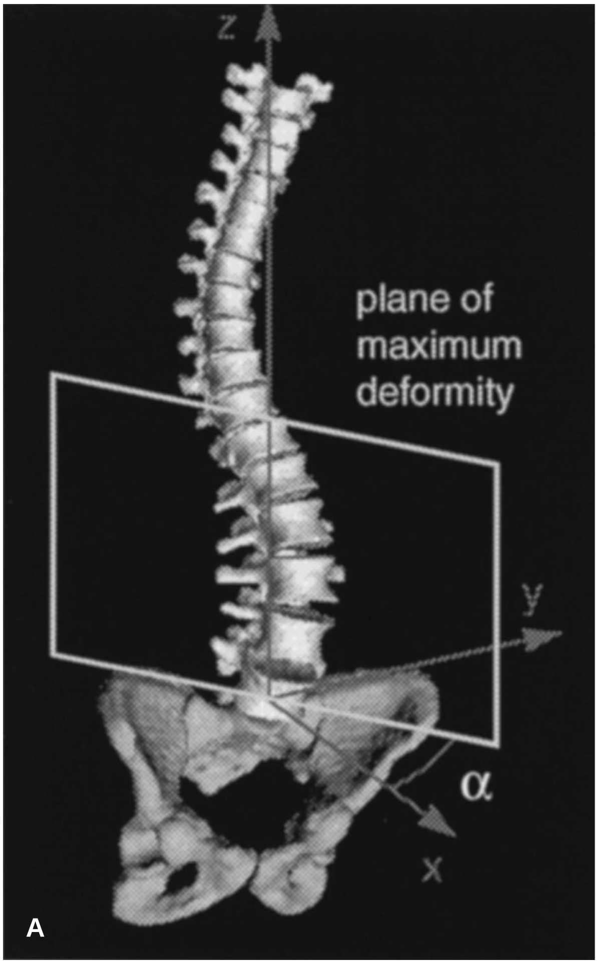


Fig. 1 A–C Graphical representation of the 3D reconstructed vertebral landmarks of the same patient before surgery *(left)*, at short-term *(middle)*, and long-term *(right)* follow-up in **A** frontal view, **B** lateral view, and **C** top view



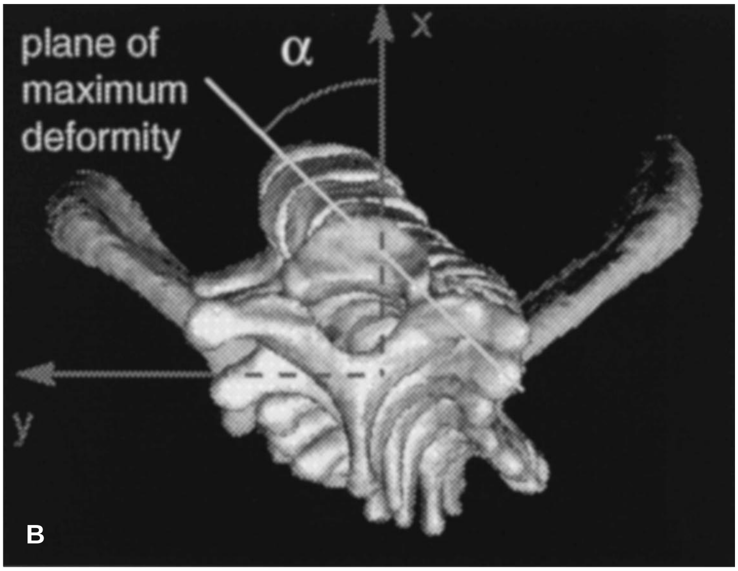


Fig. 2 A, B The plane of maximum deformity of the lumbar curve **A** in three-quarter profile view and **B** in top view. Its orientation (α) is measured from the sagittal plane

purposes. The first radiograph is a conventional postero-anterior view, while the second is a lateral view, obtained by turning the patient 90° around the vertical axis. This is done with the help of a specially designed turning platform inside the positioning apparatus on which the patient stands during all the X-rays. On each radiograph, the following anatomical landmarks are identified and interactively marked from T1 to L5: the superior and inferior tips of both pedicles and the superior and inferior center of each end plate. Images of each anatomical landmark and the 50 steel balls of the calibration object are then interactively digitized on a custom-made digitization computer program [7] to obtain their 2D coordinates. From these, the 3D coordinates of each landmark are calculated using the Direct Linear Transformation algorithm [19]. They can then be visualized in any desired projection on a computer workstation (Fig. 1).

A parametric model based on anthropometric data can also be generated to obtain a graphic representation, which is easier to interpret [11]. Finally, the following geometrical parameters of the spine were computed from the 3D coordinates of the anatomical landmarks for each reconstruction:

1. Computerized Cobb angle of the thoracic or lumbar curve in the frontal and sagittal planes. This is an equivalent of the Cobb angle, which is computed in any specified vertical projection of the 3D curve passing through the centroid of the four landmarks on the pedicles (pedicle centroid line) by calculating the angle between the intersection of two lines perpendicular to the curve at its inflexion points. The computerized pedide Cobb angle is slightly higher (1.13 times) than the conventional Cobb angle, but is highly correlated with it ($r = 0.97$) [24].

2. Orientation of the plane of maximum deformity. This plane is obtained by rotating the spine around the vertical axis until a maximum Cobb angle value is measured (Fig. 2). The orientation of the plane is measured as the angle between this plane and the sagittal plane. In a normal thoracic spine without scoliosis, the orientation of the plane of maximum curvature should be 0°, since the only curves are the thoracic kyphosis and lumbar lordosis, which lie in the sagittal plane. In a moderate to severe scoliosis, this plane lies

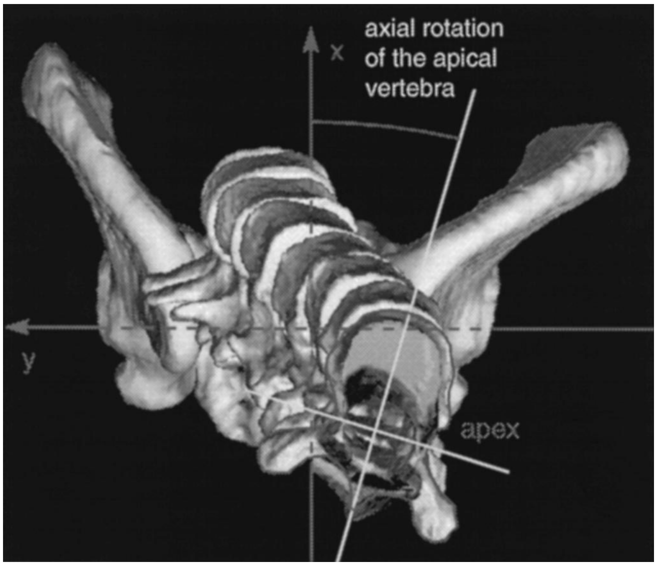


Fig. 3 Apical vertebral rotation

in an intermediate position between the frontal and sagittal planes, usually closer to the frontal plane.

3. Apical vertebral axial rotation using a computerized approach of the method described by Stokes et al. [23] (Fig. 3).

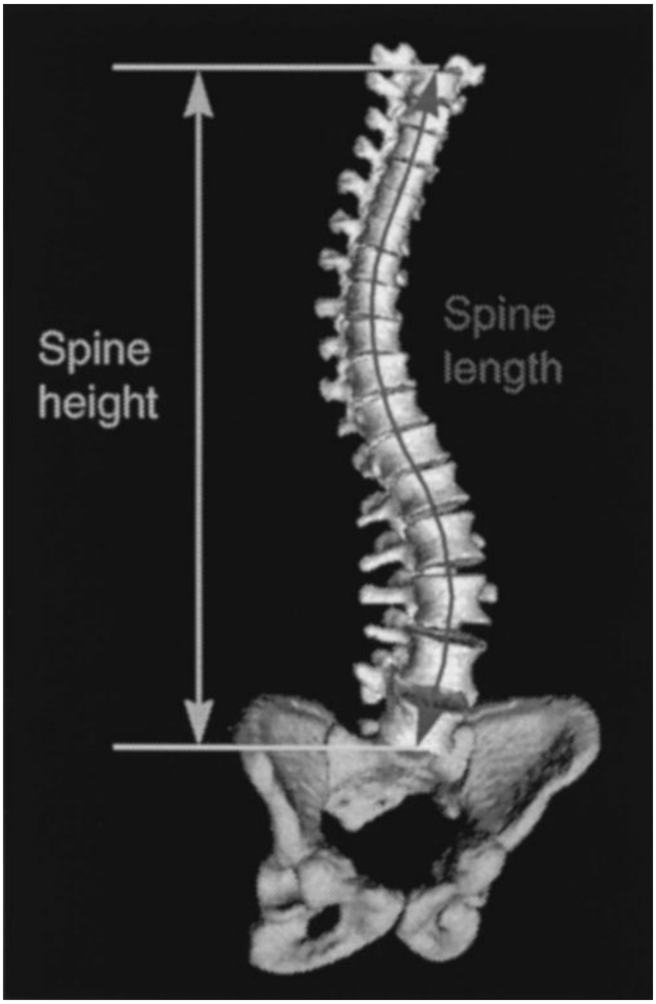


Fig. 4 Spinal length and height

4. Spinal length. This is the 3D length of the vertebral body line from T1 to L5, calculated as the sum of the 3D length of each line segment joining the center of adjacent vertebral bodies (Fig. 4).

5. Spinal height. This is the vertical distance between the center of the vertebral bodies of T1 and L5. In a perfectly straight spine with no curve in the sagittal or frontal plane, the spinal height should be equal to the spinal length. For normal and scoliotic subjects, the spinal height is always smaller than the spinal length (Fig. 4).

The accuracy of 3D reconstructions has been measured [5] at 2.1 ± 1.5 mm. The variability of the geometric parameters calculated from the 3D models has been shown to be smaller or within the inter- and intra-observer errors of similar clinical measurements made on radiographs with various rulers or goniometers [16].

Results

Every geometric parameter measured for the entire group was compared at stages I, II and III using paired two-sided Student *t* tests. The level of significance was set at 0.05. Results for all geometric parameters are provided in Table 1. Cobb angles measured in the frontal plane and in the plane of maximum deformity are reported as absolute values since the side of the curve is not considered a significant clinical factor for the correction. Cobb angles in the sagittal plane are reported in signed value (positive: anterior concavity; negative: posterior concavity), since some cases were aggravated (thoracic curves becoming lordotic or lumbar curves becoming kyphotic). The orientation of the plane of maximum deformity is reported as an absolute value relative to the sagittal plane, which means that if the maximum Cobb angle is measured in the frontal plane, the orientation of the plane of maximum deformity is 90° while if the curve is "anatomically correct" the plane of maximum deformity is 0°. Axial rotation of the apical vertebra is also reported as an absolute value. Spinal length and height are reported in millimeters. A typical example of a 3D reconstruction for one subject at the three stages is illustrated in Fig. 1.

In the frontal plane, the thoracic curve correction averaged 48%, from a mean Cobb angle of 58° preoperatively

Table 1 Means values, standard deviations, and levels of significance (*P*) for geometric parameters in the group of subjects (*T* thoracic spine, *L* lumbar spine)

Parameters	Stage I	Stage II	Stage III	*P* (I vs II)	*P* (II vs III)	*P* (I vs III)
Frontal Cobb angle (°)						
T	58 ± 14	30 ± 16	37 ± 14	7×10^{-13}	2×10^{-4}	4×10^{-10}
L	54 ± 10	35 ± 13	38 ± 9	4×10^{-8}	0.2	4×10^{-8}
Sagittal Cobb angle (°)						
T	32 ± 18	39 ± 16	41 ± 13	0.02	0.2	3×10^{-4}
L	25 ± 18	27 ± 16	29 ± 12	0.7	0.7	0.3
Orientation of plane of maximum deformity (°)						
T	75 ± 9	56 ± 17	56 ± 18	2×10^{-6}	0.953	5×10^{-7}
L	70 ± 16	57 ± 19	61 ± 16	7×10^{-4}	0.494	0.089
Apical vertebral axial rotation (°)						
T	21 ± 9	15 ± 8	17 ± 10	6×10^{-3}	0.2	0.1
L	16 ± 10	11 ± 8	12 ± 7	6×10^{-3}	0.2	0.1
Spinal length, T1–L5 (mm)	384 ± 24	394 ± 24	401 ± 21	2×10^{-13}	4×10^{-4}	4×10^{-9}
Spinal height, T1–L5 (mm)	351 ± 29	375 ± 27	376 ± 22	3×10^{-12}	0.5	7×10^{-11}

to 30° postoperatively, while in the long term 25% of that correction was lost giving a resulting Cobb angle averaging 37°. The 35% lumbar curve correction (from 54° to 35°) obtained in the days following surgery was not significantly affected in the long term and was maintained at an average of 38° of Cobb angle. In the sagittal plane, the thoracic kyphosis was slightly increased following surgery, from an average of 32° preoperatively to 39° postoperatively, and remained stable in the long term (41°), while lumbar lordosis remained unchanged at all three stages. The plane of maximum deformity underwent a significant saggitalisation, from 75° to 56° for thoracic curves and from 70° to 57° for lumbar curves after surgery, and these changes remained stable at 2.5 years follow-up. As noted by many authors [1, 15, 26], only minimal changes in apical vertebral axial rotation could be detected: 6° and 5° of average correction for thoracic and lumbar curves respectively, which remained unchanged in the long term. These differences are within the variability of the measurement technique, which has been shown [23] to be ± 3°. Finally, spinal length and height were significantly increased by the surgical procedure (from 384 mm to 394 mm and from 351 mm to 375 mm), but the length increased less than the height (+10 mm compared to +24 mm), indicating that the spine was straightened during the surgery. At follow-up, only the spinal length continued to increase significantly for another 7 mm.

Discussion

Idiopathic scoliosis has been recognized as a 3D deformity for over a century [2, 14, 24], but it is only recently, with the introduction of CD instrumentation and similar multi rod, hook, and screw systems, that surgeons have started to focus on gaining 3D correction of the spinal deformity [27]. Recent reports have clearly documented adequate 3D correction of the spinal shape after surgery on X-rays [8, 18] and 3D reconstructions [17], but the stability of these changes over time and the immediate and long-term changes in orientation and length of the spine after surgery have received very little attention.

This study demonstrates that significant changes in spinal shape and length do occur in the years following instrumentation and fusion of the spine in adolescent girls. Short-term changes (stage I vs II) reflect mostly the correction achieved by the instrumentation, while long-term changes (stage II vs III) reflect mostly adaptive changes and continued growth of the spine. The short-term changes are consistent with previously reported results and confirm that adequate 3D correction of the spinal shape can be achieved with significant improvements of the Cobb angle in the frontal plane and in the plane of maximum deformity, as well as significant improvement and sagittalisation of the plane of maximum deformity, while the normal sagittal curve profile is maintained. This is an important difference as compared to previous instrumentation systems such as Harrington instrumentation, which tended to improve the curve in the frontal plane, but at the expense of a decrease in the thoracic kyphosis, and produced only minimal change in the orientation of the plane of maximum deformity [1, 22]. These differences indicate a significant advantage of the multi rod, hook, and screw system over previous instrumentation systems. As previously reported, changes in apical vertebral rotation are modest [3]. It should be noted, however, that the average curve correction in the frontal plane for lumbar curves is smaller than that previously reported by the same group of surgeons [12, 17] , which may indicate a “selection bias” in this particular group of patients. Whether this difference reflects a variation in operative technique or in curve stiffness could not be determined from our clinical review of this cohort of subjects.

The long-term changes in spinal shape observed in the present study indicate that there is a significant loss of curve correction in the frontal plane for thoracic curves, which is accompanied by a significant increase in spinal length, while the spinal height remains unchanged. This continued growth of the spine after posterior instrumentation and fusion coupled with the curve deterioration and the lack of change in spinal height strongly suggests that these long-term changes are caused by a crankshaft phenomenon. This phenomenon is well known to occur in young immature spines after spinal fusion [13], but its occurrence in older post-menarchal adolescents with idiopathic scoliosis has not been well documented. Unfortunately, we could not determine from this study to what extent this increase in 3D spinal length occurred in the fused or unfused segments of the spine, but the absence of curve deterioration in the lumbar spine suggests that most of the increase in spinal length was in the thoracic spine. It should also be noted, that patients in the study were asymptomatic and none were suspected of presenting pseudarthrosis from their clinical evaluation. The changes in spinal length were not detected at short-term follow-up, and this indicates that slippage of the instrumentation and/or relaxation of soft tissues around the instrumentation are not responsible for the observed loss of correction, since they occur in the first few weeks or months following surgery. Coupled with the documented loss of correction, these observations confirm that results of surgical treatment for idiopathic scoliosis should be reported with a minimum of 2 years follow-up in order to provide an adequate assessment of the effect of the surgery on spinal curve and length.

Conclusion

Significant 3D changes in curve correction and spinal length were documented immediately after posterior instrumentation and fusion of the spine in a cohort of adolescents with idiopathic scoliosis using multi rod, hook and screw systems. These changes, however, were not stable over time, and differed between the short- and long-term follow-up. A significant curve deterioration coupled with an increase in spinal length was noted between the immediate postoperative period and the follow-up, at an average of 2.5 years, suggesting that the crankshaft phenomenon plays a significant role in long-term 3D changes after spinal instrumentation and fusion. These changes can occur even in post-menarchal adolescents, and indicate that a mimimum period of 2 years of follow-up should be obtained before reporting the clinical results of surgery in adolescent idiopathic scoliosis.

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