# Long-Term (Over Five Years) Results of Surgical Correction of Scheuermann's Kyphosis

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# Abstract

**Study design.** Retrospective cohort study.

**Objective.** The study objective is to assess long-term results of surgical correction of kyphosis due to Scheuermann's disease.

**Summary of Background Data**. Despite a large number of studies on surgical correction of juvenile kyphosis, articles discussing long-term (over five years) results of these interventions are very rare.

**Methods**. The study group included 43 patients (m/f ratio, 34/9). The mean age was 19.1 (14–32) years; the mean postoperative follow-up was 6 + 10 (5–20) years. Two-stage surgery including discectomy and interbody fusion followed by posterior correction and fusion was conducted in 35 cases (group A). Eight patients (group B) underwent only posterior correction and spinal fusion. The following parameters were determined for each patient: Thoracic Kyphosis (TK); Lumbar Lordosis (LL), Sagittal Vertical Axis (SVA); Sagittal Stable Vertebra (SSV); First Lordotic Vertebra (FLV); Proximal Junctional Angle (PJA); and Distal Junctional Angle (DJA). All measurements were performed immediately before surgery, one week after surgery, and at the end of the follow-up period. All patients answered the SRS-24 questionnaire after surgery and at end of the follow-up.

**Results**. Groups A and B were comparable in age and sex, BMI and initial Cobb angle ($P < 0.05$). The curve decreased from 77.8° to 40.7° in group A and from 81.7° to 41.6° in group B. The loss of correction was 9.1° and 6.0° in groups A and B, respectively. At ID < 1.2, deformity correction and correction loss were 35° (44.0 %) and 7.1°, respectively; at ID ≥ 1.2, deformity correction and correction loss were 44.5° (54.7 %) and 3.9°, respectively ($P < 0.05$).

Proximal junctional kyphosis was detected in 21 out of 43 patients (48.8 %). The rate of PJK was 45.4 % in those patients whose upper end vertebra was included in the fusion and 60 % in individuals whose upper end vertebra was not included. PJK developed in eight (47.8 %) out of 17 patients who received ≥ 50 % kyphosis correction and in 13 (50 %) individuals who had < 50 % deformity correction. The rate of DJK development was 39.5 %. The lower instrumented vertebra (LIV) was located proximal to the sagittal stable vertebra in 16 cases, with 12 of them being diagnosed with DJK (75 %). In 27 patients, LIV was located either at the SSV level or distal to it, the number of DJK cases was 5 (18.5 %) ($P < 0.05$). Only two patients with complications required unplanned interventions. According to the patient questionnaires, the surgical outcome score increases between the immediate and long-term postoperative periods for all domains and from 88.4 to 91.4 in total. The same applies to answer to the question No. 24 ("Would you have the same treatment again if you had the same condition?"): rate of positive answers ranges from 82 to 86 %.

**Conclusions.** Two-stage surgery, as a more difficult and prolonged one, has no advantages over one-stage operation in terms of magnitude and stability of the achieved effect. The problem of choosing the

area of spinal fusion is far from being solved. Surgical treatment improves the quality of life of patients with Scheuermann's disease; the improvement is also observed in the long-term postoperative period.

## Introduction

Many years have passed since Scheuermann's disease was recognized as an independent pathology with specific clinical and radiological manifestations, as well as course patterns [1–3]. The first results of surgery for severe progressive forms of the disease turned out to be quite successful to inspire orthopedists in many countries to continue this study [4]. The number of publications on this topic has been increasing over the years. However, there are a number of issues, which are, apparently, too far from being solved. It was originally believed that two-stage intervention, which includes discectomy, interbody fusion, and deformity correction using spinal instrumentation, provides optimal correction with its minimal loss [5–8]. Incorporation of pedicle fixation into the medical practice and its common use have allowed many surgeons to abandon the anterior treatment stage [9–12]. However, no final consensus has been reached yet. Another issue is development of proximal and distal junctional deformities, a certain percentage of which require unplanned reoperations. The collective experience of many surgeons has made it possible to determine a number of risk factors for the development of these deformities; however, even these recommendations are not always applicable [13–18]. The data of assessing the quality of life of patients after surgery using various questionnaires provides an ambiguous picture [19–22]. In addition, studies on the long-term (over five years) results of surgical treatment are quite rare in contrast to a large number of works on surgical correction of juvenile kyphosis [23–26]. The main aim of the current study is to partially fill this gap by presenting data that are not entirely consistent with the results of other authors.

## Materials And Methods

***Patients.*** A total of 213 patients with kyphosis due to Scheuermann's disease have been operated on at the Clinic for Pediatric and Adolescent Spine Surgery of Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan starting from 1997. Among them, 152 individuals were operated on before October 2015, which means that the actual period of postoperative follow-up was more than five years. The complete survey dataset was available for 43 patients, who comprised the study group. There were 34 boys and nine girls in the group. The mean age was 19.1 (14–32) years. The mean postoperative follow-up was 6 (5–20) years.

A total of 28 patients complained of pain (either persistent or intermittent) in the thoracic and lumbar spine upon admission to the clinic; all participants were unsatisfied with their appearance. Two individuals showed mild symptoms of pyramidal insufficiency during overhead traction.

***Radiological examination.*** Radiography of the thoracic and lumbar spine including the pelvis and the femoral heads was performed in an upright position. All measurements were conducted by experienced

radiographers not involved in the clinical management of the patients. The following parameters were determined for each patient:

thoracic kyphosis (TK); lumbar lordosis (LL); sagittal vertical axis (SVA); the level of sagittal stable vertebra (SSV), which is the vertebral body most evenly divided in half by the vertical line passing through the posterior-superior angle of $S_1$ (SSV-B, where B stands for bisected) [27]; proximal junctional angle (PJA), namely the angle between the caudal endplate of the upper instrumented vertebra (UIV) and the cranial endplate of vertebra located two levels caudal to the UIV; distal junctional angle (DJA), which is the angle between the cranial endplate of the lower instrumented vertebra (LIV) and the caudal endplate of the inferior vertebra.

All measurements were taken immediately before the surgery, one week after it, and at the end of the follow-up period. All patients answered the SRS-24 questionnaire after surgery and at the end of the follow-up.

***Surgical technique***. All patients were operated on using modern segmental instrumentation. The correction stage was preceded by the ventral procedure, namely discectomy and interbody fusion with autologous bone graft (group A), in 35 cases. The remaining eight individuals were operated on using posterior approach only (group B). All the operations mentioned in this study were performed by three surgeons, each of whom has more than 25 years of experience in spinal surgery.

The two-stage intervention was initiated with anterior release. Transthoracic approach was carried out through the base of the rib corresponding to the spinal segment located two levels cranial to the kyphotic apex. A total of 3–5 discs at the kyphotic apex including the endplates of adjacent vertebrae up to the posterior parts of the annulus fibrosus were resected using osteotomes and forceps. Intervertebral defects were filled with bone chips from the rib resected during the approach. The patient was then turned to the prone position. The posterior parts of the vertebrae included in the fusion were exposed at the required length through the posterior medial approach. Fixation elements, namely hooks and/or pedicle screws, were implanted in accordance with the preoperative planning. Thus, one of the three types of instrumentation was used: either hook, hybrid or pedicle screw fixation. Ponte osteotomy [28] was usually performed at three levels at the kyphotic apex. The rods were contoured to the physiological curvatures of the thoracic and lumbar spine and attached to the heads of fixation elements at the cranial end of the instrumentation first. Further correction was carried out using lever reduction and apical compression. Heads of the fixation elements were tightened. The cortical bone was accurately removed from the posterior vertebral elements along the fusion area, and spinal fusion with autologous bone was conducted. No external immobilization was used. The area of spinal fusion was 11.6 (10–13) vertebral motion segments. The duration of one-stage and two-stage interventions was 206 (90–395) and 272 (160–480) min, respectively. The mean blood loss was 788 (150–2,050) and 1,009 (350–3,250) mL in posterior and anterior–posterior approaches, respectively.

***Statistical methods.*** Descriptive characteristics for continuous data are presented as median [first quartile (Q1); third quartile (Q3)], arithmetic mean ± standard deviation. The distributions of parameter values in the groups were compared using the unpaired Mann–Whitney U test with calculating the distribution bias and the 95 % confidence interval (CI) for the bias. Complications are presented as quantity, % [95 % CI of the percent calculated using the Wilson formula]. Complications were compared using the two-tailed Fisher's exact test with calculating the odds ratio (OR) of complications and constructing a 95 % CI for OR. Statistical hypotheses were tested at the critical level of significance of P = 0.05, i.e., the difference was considered statistically significant at P < 0.05.

All statistical calculations were carried out using the RStudio software package (version 1.3.959 – © 2009-2020 RStudio, Boston, USA, URL https://www.rstudio.com/) in the R language (versions 4.0.2 (2020-06-22), URL https://www.R-project.org/)

The study was approved by the Local Ethical Committee of Novosibirsk Research Institute of Traumatology and Orthopedics . Ya.L. Tsyvyan; All patients gave their informed consent to participate in the study. All experiments and methods were performed in accordance with relevant guidelines and regulations.

# Results

The patients were divided into two groups. Group A patients underwent anterior release, posterior correction with instrumentation, and spinal fusion. Individuals in group B were subjected to posterior correction with instrumentation and spinal fusion. There were 35 and 8 patients in groups A and B, respectively. The groups were comparable in age, sex, BMI, and initial Cobb angle (see Table 1).

Table 1. Participant characteristics (age, male/female, BMI, Cobb angle) in groups A and B

| Table | Group A | Group B | P value |
|---|---|---|---|
| Mean patient age (years) | 19.2 (14–28) | 18.7 (14–33) | 0.572 |
| Male to female ratio | 6 : 2 | 26 : 9 | > 0.999 |
| BMI | 19.6 (16.8–22.6) | 20.8 (16.9–31.6) | 0.587 |
| Initial Cobb angle of kyphosis | 81.7(64–105) | 77.8 (62–87) | 0.288 |

The achieved correction significantly exceeds the preoperative mobility in the general group (Table 2). The resulting correction was 48.6 % of initial kyphosis and maintained at 86.3 % of the achieved level during the entire follow-up. The two subgroups (with and without anterior surgery) demonstrate practically the same pattern. The initial Cobb angle in group A was less than that in group B. The achieved correction was also slightly smaller in group A; the postoperative loss of correction was greater in both absolute and percentage values in group A. One can state that the anterior release (group A) does not provide any advantages in terms of both the correction rate and its maintenance.

Table 2. Changes in the Cobb angle of kyphosis in the general group depending on the surgical approach.

| | General group | Group A | Group B | P value |
|---|---|---|---|---|
| Number of patients | 43 | 35 | 8 | |
| Cobb angle before surgery | 80.6° (62–105°) | 77.8° (62–87°) | 81.7° (64–105°) | 0.288 |
| Cobb angle on supine lateral bending (mobility) | 55.5° (27–83°) (37.6 %) | 45.0° (27–48°) (41.7 %) | 57.2° (34–83°) (30.0 %) | 0.022 |
| Cobb angle after surgery | 41.4° (21–72°) | 40.7° (27–53°) | 41.6° (21–72°) | 0.790 |
| Cobb angle at the end of the follow-up | 47.9° (17–88°) | 49.8° (28–72°) | 47.6° (17–88°) | 0.628 |
| Correction (% of the initial Cobb angle) | 39.2° (48.6 %) | 37.1° (47.7 %) | 40.3° (49.3 %) | 0.492 |
| Loss of correction (% of the achieved angle) | 6.5° (13.7 %) | 9.1° (24.5 %) | 6.0° (12.1 %) | 0.696 |

As for lumbar lordosis, all parameters remained normal during the follow-up period (Table 3).

Table 3. Changes in the Cobb angle of lumbar lordosis in the general group depending on the surgical approach.

| | General group | Group A | Group B | P value |
|---|---|---|---|---|
| Number of patients | 43 | 35 | 8 | |
| Lumbar lordosis before surgery | 80.3° (48–112°) | 78.5° (60–103°) | 80.7° (48–112°) | 0.444 |
| Lumbar lordosis immediately after surgery | 52.8° (33–132°) | 51.6° (34–73°) | 52.2° (33–132°) | 0.950 |
| Lumbar lordosis at the end of the follow-up | 57.1° (36–89°) | 62.1° (52–79°) | 53.8° (42–89°) | 0.229 |

Implant density (ID), which is defined as the ratio of the number of fixation elements (hooks/screws) to the number of vertebrae involved in fusion, depends on instrumentation type. The mean ID is 0.89 and 1.68 for hook and hybrid/pedicle-screw fixation, respectively (Table 4). Hook fixation reduces kyphosis from 79.7° to 44.7°, while hybrid/pedicle-screw fixation decreases the angle from 82.2° to 37.3°. Thus, the use of pedicle screw instrumentation allows for a significant increase in the correction rate (44.9°, 54.7 %) compared to hook fixation (35°, 44 %) and its better maintenance (loss of correction, 3.9° versus 7.1°).

Table 4. Changes in the Cobb angle of kyphosis at different Implant Density values

| | Hooks | Hybrid/pedicle-screw instrumentation | P value |
|---|---|---|---|
| Number of patients | 24 | 19 | |
| ID | 0.89 (0.36–1.2) | 1.38 (0.8–1.75) | 0.001 |
| Cobb angle before surgery | 79.7° (66–100°) | 82.2° (64–105°) | 0.440 |
| Cobb angle immediately after surgery | 44.7° (28–72°) | 37.3° (21–54°) | 0.048 |
| Cobb angle at the end of the follow-up | 51.8° (30–88°) | 41.2° (22–72°) | 0.009 |
| Correction (%) | 35° (44 %) | 44.9° (54.7 %) | 0.026 |
| Loss of correction | 7.1° | 3.9° | 0.020 |

Proximal junctional kyphosis was diagnosed in 21 out of 43 patients (48.8 %). Of 33 patients with the upper end vertebra of the curve included in the fusion, PJK was detected in 15 (45.4 %) individuals, including two cases of severe kyphosis with subluxation of the vertebra superior to the UIV. These two patients underwent unplanned interventions. All the other individuals with PJK were asymptomatic. PJK developed in six (60 %) out of 10 patients in whom the upper end vertebra was excluded from the fusion. There were no statistically significant differences between the subgroups (P = 0.448). PJK was diagnosed in eight (47.8 %) out of 17 participants with kyphosis correction of ≥ 50 % and in 13 (50 %) out of 26 individuals with deformity correction of < 50 %. Since pedicle and transverse hooks were used for formation of the upper end grip in all cases, the ligamentum flavum was not injured. For this reason, this factor was excluded from the list of possible causes of frequent PJK cases.

The following changes were revealed at the distal end of instrumentation. The angle formed between the cranial endplate of the LIV and the caudal endplate of the distal vertebra averaged 16.9° before surgery, 9.8° immediately after surgery, and 10.1° at the end of the follow-up in the general group (Fig. 1 ) The final angle was < 10° in 17 individuals. In addition, two cases of kyphosis (2° and 7°) were noted. The DJK rate was 39.5 % in the general group. LIV was located proximal to the SSV in 16 cases. Of them, 12 patients (75 %) developed DJK. LIV was found either at the SSV level or distal to it in 27 patients; there were five (18.5 %) DJK cases. Thus, a significant difference between these two subgroups (P < 0.001) was noted. There were no indications for unplanned intervention among DJK patients.

Assessing the sagittal balance is hampered by the diversity of pre- and postoperative parameter values. We can only state that negative balance was noted in 54 % of patients before surgery, 36 % of individuals immediately after surgery, and in 81 % of cases at the end of the follow-up. The sagittal balance varied from – 89 to + 108 mm.

The surgical outcome score increases for all domains between the early and late postoperative periods; however, the differences are insignificant (Table 5). Statistically significant changes were noted for the following domains: pain, function after surgery, general function, and function–activity. The total score increased proportionally as well. The same applies to answer to the question No. 24 (consent to undergo the same surgical treatment if necessary): the score grew from 82 to 86 %.

Table 5. The results of HRQoL assessing using the SRS-24 questionnaire

| | early | late | P value |
|---|---|---|---|
| **pain** | 3.74 ± 0.56 | 3.81 ± 0.52 | 0.009 |
| **general self-image** | 3.96 ± 0.58 | 4.12 ± 0.55 | 0.072 |
| **self-image after surgery** | 4.39 ± 0.48 | 4.45 ± 0.43 | 0.062 |
| **function after surgery** | 2.03 ± 1.18 | 2.32 ± 1.43 | 0.030 |
| **general function** | 3.10 ± 0.75 | 3.26 ± 0.84 | 0.042 |
| **function–activity** | 3.50 ± 0.74 | 3.68 ± 0.71 | 0.036 |
| **satisfaction with surgery** | 4.43 ± 0.51 | 4.49 ± 0.56 | 0.057 |
| **consent to undergo the same surgical treatment if necessary (question No. 24)** | 82 % | 86 % | |
| **grand total** | 88.4 | 91.4 | 0.058 |

Fourteen (32.5 %) out of 43 patients had 16 complications in total. The most frequent complications (11 cases) were the ones associated with implants: rod/screw fractures and hook displacement (Fig. 1C). Six individuals required reoperation. Proximal Junctional Failure (PJF) accompanied by severe kyphosis due to subluxation of the vertebra superior to the UIV was noted in two cases. Both patients required extension of the instrumentation to the cranium. The operation did not provide the desired result immediately. These two patients underwent seven unplanned surgeries in total. Other complications included pyelonephritis and spontaneous pneumothorax, which were successfully treated by conservative treatment. There were neither neurological nor purulent complications.

# Discussion

As far as we can judge, there are very few studies on the long-term results of surgical correction of juvenile kyphosis, while both the treatment strategy and the outcomes seem to be ambiguous.

Apparently, the first study of this kind was published by Soo et al. [23] in 2002. The authors evaluated the outcomes of three strategies used for treating 63 patients: observation and exercise, bracing, and surgical correction using Harrington compression rods following anterior release. The results were followed up for 14 (10–28) years. The main examination methods were radiography and surveys using a questionnaire designed by the authors. The kyphotic curves in patients of the three subgroups were 57°, 64°, and 73° before surgery, and 57°, 51°, and 59°, respectively, at the end of the follow-up. About half of the achieved correction (20 out of 37 cases) was lost in the surgery group. The achieved kyphotic curvatures were almost identical in the three subgroups by the end of the follow-up period.

The questionnaire results demonstrated no differences in the following parameters between the patents: marital status, general health, educational level, work status, pain degree, and functional capacity. There was no relationship with the treatment mode, as well as type and degree of the kyphotic curve. Patients of the brace and surgery subgroups noted the greatest improvement in their self-image among other participants, attributing it to the treatment. The lowest functional level was observed in patients with deformities of ≥ 70° by the end of the follow-up.

The authors conclude that careful selection of the method for treating patients with Scheuermann's disease should be based on age, deformity type, and pain severity.

In 2009, Denis et al. [24]. investigated the frequency and risk factors for the development of junctional kyphosis after surgical correction of kyphotic deformities due to Scheuermann's disease. The authors analyzed the results of the treatment of 67 patients who were operated on at least five years ago (mean follow-up, 73 months). A total of 15 individuals underwent one-stage posterior intervention; 52 patients were treated by two-stage surgery. Traditional definitions were used to identify junctional kyphosis. PJK was considered if the proximal junctional angle between the cranial endplates of the UIV and the vertebra two levels cranial to it was ≥ 10° or increased by at least 10° after surgery compared to the baseline. Distal junctional kyphosis was determined by the angle between the caudal endplates of the LIV and the vertebra located one level caudal to it. The authors managed to reduce kyphosis from 78° to 45° and almost completely preserve it: the curve angle was 49° at final follow-up. PJK developed in 20 patients (30 %). The frequency of PJK was 8 % if the proximal end vertebra in the curvature was included in the fusion and 63 % if it was not. The authors mention damage to the ligamentum flavum by a hook or a sublaminar wire as the second most important cause of PJK. PJK development is associated with neither the baseline kyphosis magnitude nor the achieved correction rate. DJK was detected in eight patients (12 %), with seven of them sharing the same feature: the first lordotic disc was not included in the fusion. No correlation between the instrumentation type used and the frequency of junctional kyphosis was noted.

In 2016, Graat et al. [25] published the long-term outcomes of surgeries for Scheuermann's kyphosis in 29 patients. The postoperative follow-up was 18 (14–21) years. Posterior approach was used in 13 cases; combined (anterior–posterior) procedure was carried out in 16 individuals. The initial Cobb angle (82°) was reduced to 69° after surgery by the end of the follow-up. Unfortunately, the authors present radiography data for the general group only and do not differentiate them depending on the surgical

approach used (one-/two-stage). They only mention that the combined and posterior approaches reduced the curvature by 27 and 17 %, respectively, while not considering the difference to be statistically significant. The number of PJK cases increased with the duration of postoperative follow-up: there were nine (31 %) patients during the first year after surgery, 12 (43 %) individuals in the period of eight years after surgery, and 15 (53 %) cases by the end of the follow-up period. The upper end vertebra was fused in eight patients (four PJK cases) and not included in the instrumentation in 19 individuals (11 PJK cases). No revision surgeries for PJK were performed. There were no reported cases of DJK. Implant-associated complications were observed in 20 patients (69 %) and distributed approximately equally between the two subgroups. Implants were removed in seven individuals; a solid bone fusion was visually confirmed in all of the cases. The correction loss was 5° after implant removal. HRQoL was assessed using the Oswestry Disability Index, Visual Analog Score Pain (SF-36), and EQ-5d. A total of 21 (72 %) out of 29 patients were satisfied with the treatment outcome and would be willing to undergo the same treatment again if they had a similar condition, while the remaining 23 (79 %) participants recommended the procedure to others. The authors consider the radiographic results of surgical treatment as "disappointing". However, they also reasonably correlate them with the data of clinical studies indicating high functional activity of patients for many years after surgery even with a high incidence of postoperative pain. In addition, the patients who underwent the combined surgical treatment demonstrated better functional results than those subjected to posterior fusion only. Despite the ambiguity of the obtained results, the authors note that the outcomes are better than in case of natural disease course, as far as it can be judged from the literature.

In 2019, Chang Ju Hwang et al. [26] published the results of all-pedicle-screw fixation in individuals with kyphosis of various etiologies, including Scheuermann's disease. Juvenile kyphosis was diagnosed in 15 out of 43 patients. The mean postoperative follow-up was 5.8 (5–9.7) years for these 15 individuals. The average age of the patients with Scheuermann's disease was 19.1 years. Vertebral column resection was conducted in 11 cases in order to increase the mobility of the spinal deformity. The authors chose the length of the instrumented fusion based on the following principles: the number of vertebra involved in fusion should be symmetrical both above and below the kyphosis apex, provided that the disc located cranial to the UIV is lordotic. Kyphosis was 91° at baseline, 48.1° immediately after surgery, and 49.9° at the end of the follow-up, i.e. the average correction rate was only 1.8°. Complications included two cases of PJK, one screw pullout, and one case of signal loss during spinal neuromonitoring, which were followed by complete recovery. Evaluation of the quality of life (ODI and SRS-30) showed significant improvement in all domains.

Our data confirm that the combined approach has no advantages over the use of one type of instrumentation. Furthermore, posterior intervention made it possible to obtain a slightly larger correction and its better preservation.The rate of junctional kyphosis was significant in the group we studied: 48.8 % for PJK and 39.5 % for DJK. Moreover, the overwhelming majority of the cases were asymptomatic and did not require reoperation. Spinal fusion was successfully extended to the cranium in only two PJK cases with kyphosis reaching 90°, which can be interpreted as proximal junctional failure (PJF). PJK usually develops when UIV is excluded from the fusion, but the differences are insignificant. According to

our data, the rate of the major curve correction is not a risk factor for PJK. As for the distal end of the fusion, adverse changes in the disc caudal to the LIV occur immediately after surgery and further deteriorate. As far as we can judge, choosing SSV as the LIV seems reasonable.

We did not find any literature data on the effect of ID on the outcome of juvenile kyphosis correction. According to our data, an increase in ID due to a gradual transition from hook to pedicle crew fixation is accompanied by growth in the achieved deformity correction and yields more stable results.

We used the SRS-24 questionnaire and noted improvement for all the seven domains, although it was not statistically significant in all cases. The consent to have the same surgery if required increased from 82 to 86 %.

One of the main drawbacks of our work is the relatively small number of patients included in the study. Only 43 out of 152 participants with more than five-year follow-up considered it necessary and possible to undergo examination after the end of the follow-up period. Firstly, it can be explained by the distant clinic location relative to the patient and, hence, the high trip cost. Secondly, this can be also due to the alleged fact that the patients did not consider it necessary to undergo another examination in the absence of complaints. We also did not present any data on changes in the spinal and pelvic parameters. This is because the clinic lacked the opportunity to perform radiography with inclusion of the femoral heads for a significant period. Hence, we are unable to present the pelvic incidence and pelvic tilt parameter values. We considered it wrong to present the results of changes in the sacral slope only in the absence of other parameters.

# Conclusion

The results of long-term (over five years) follow-up of patients operated on for severe kyphosis due to Scheuermann's disease show that the issue is complicated and from being solved. It is apparent that one-stage surgery including posterior correction and spinal fusion is superior to two-stage procedure (anterior release and posterior correction) because it is less traumatic and does not show worse results. The issue of determining the length of spinal fusion is still unsettled, as indicated by a large percentage of cases with development of junctional kyphosis, both proximal and distal types. At the same time, there is a reason to believe that surgical treatment improves the quality of patients' life, and this improvement is maintained for a long period.

# Declarations

**Author contributions**. MVM – substantial contributor to the concept design, study planning, data interpretation, revision of the manuscript, and final approval of the manuscript, EVG - – substantial contributor to the concept design, SRS questionnaire analysis, final approval of the manuscript, LVL – substantial contributor to statistical analysis, revision of the manuscript, and final approval of the

manuscript, AAA - substantial contributor to the concept design, study planning, revision of the manuscript, and final approval of the manuscript.

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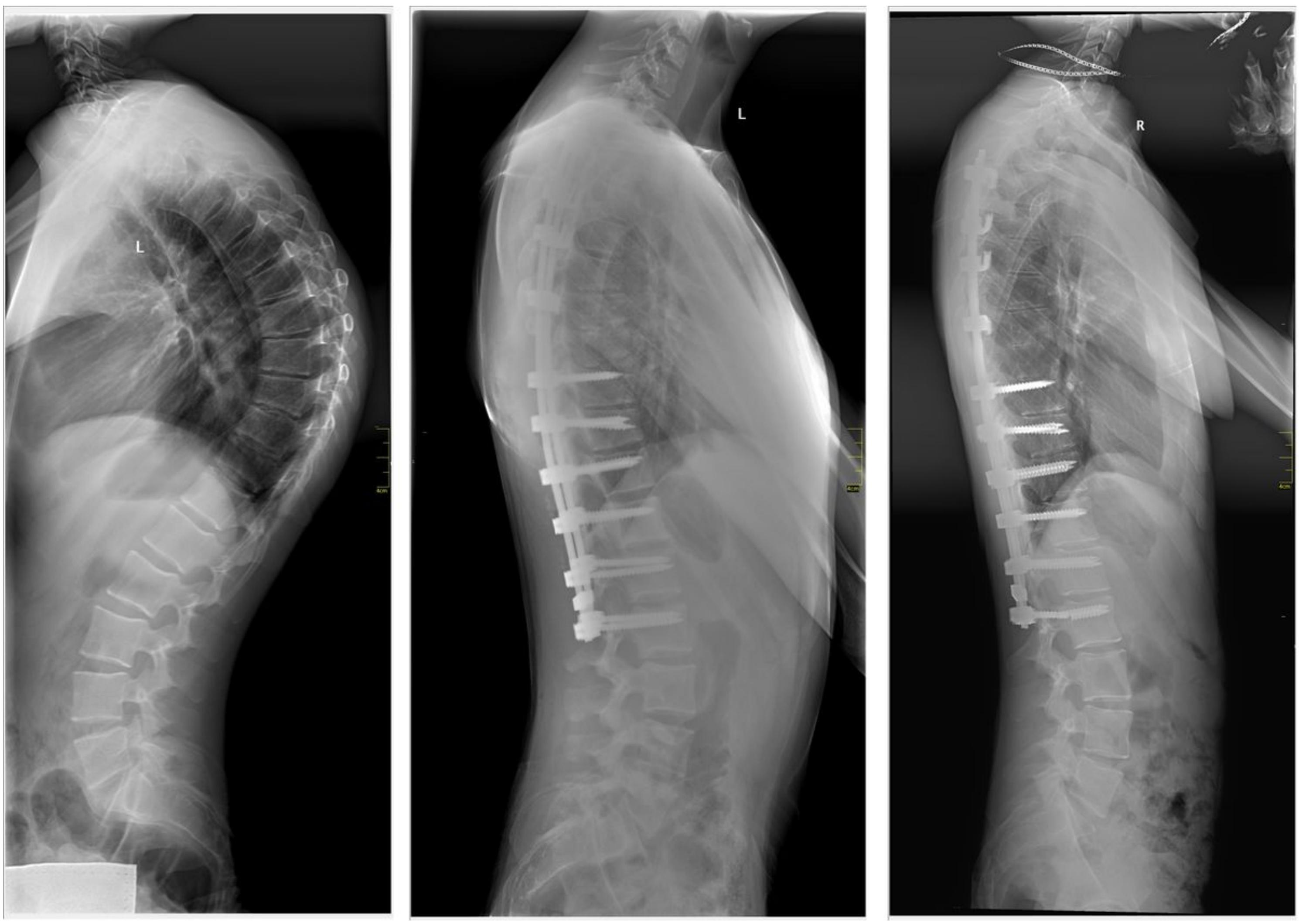
## Figures



### Figure 1

A 14-year-old patient operated on using the hybrid approach. (a) before surgery: thoracic kyphosis, 90°; lumbar lordosis, 84°; DJA, 26°; (b) 10 days after surgery: thoracic kyphosis, 21°; lumbar lordosis, 60°; DJA,

16°; (c) six years after surgery: thoracic kyphosis, 22°; lumbar lordosis, 69°; DJA, 6°. One of the distal screws was broken without fragment displacement.