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# Complications Following Surgery for Adult Scheuermann's Kyphosis: A 2-Year Follow-Up in 22 Patients

Martin HEEGAARD, Tanvir Johanning BARI, Søren OHRT-NISSEN, Martin GEHRCHEN

Rigshospitalet, Department of Orthopedic Surgery, Spine Unit, Copenhagen, Denmark

**Corresponding author:** Martin HEEGAARD ✉ martinheegaard@hotmail.com

## ABSTRACT

**AIM:** To determine the rate of postoperative complications following surgery for Scheuermann's kyphosis (SK) and ascertain whether restoration to an ideal Roussouly spine type reduced the incidence of postoperative proximal junctional kyphosis (PJK).

**MATERIAL and METHODS:** We retrospectively screened all patients undergoing SK surgery at our institution (2010–2017) and excluded patients with less than two years of follow-up. Postoperative complications were identified as early or late and minor or major. Successful restoration of Roussouly spine type was assessed and patients were classified as "restored" or "non-restored." Associations between ideal Roussouly restoration and postoperative PJK were evaluated using logistic regression analysis.

**RESULTS:** The study included 22 patients with a median age of 23 (IQR, 20.0–43.8) years. Postoperative complications developed in 17 (77%) of these cases. All 17 patients developed minor complications; seven (32%) patients also exhibited major complications. PJK was diagnosed in 55% of the patients with an 18% overall two-year revision rate. Forty-four percent of the patients in the restored group developed PJK compared to 83% in the non-restored group (p=0.162). Multivariable logistic regression analysis revealed a trend towards an increased incidence of PJK in the non-restored group, albeit without statistical significance (OR, 9.4; 95% CI, 0.7–122.5, p=0.087).

**CONCLUSION:** Our study revealed that 77% of patients undergoing surgery for SK developed at least one complication with a two-year revision rate of 18%. PJK was detected less frequently in patients who were restored to their ideal Roussouly spine type, although this finding did not achieve statistical significance.

**KEYWORDS:** Scheuermann kyphosis, Postoperative complications, Proximal junctional kyphosis, Adult spinal deformity

**ABBREVIATIONS: SK:** Scheuermann kyphosis, **PJK:** Proximal junctional kyphosis, **SS:** Sacral slope, **LL:** Lumbar lordosis, **AIS:** Adolescent idiopathic scoliosis, **ASD:** Adult spinal deformity, **PSO:** Pedicle subtraction osteotomy, **PI:** Pelvic incidence, **PT:** Pelvic tilt, **SVA:** Sagittal vertical axis, **PI-LL:** Pelvic incidence minus lumbar lordosis, **UIV:** Upper instrumented vertebrae, **SD:** Standard deviations, **IQR:** Interquartile ranges, **OR:** Odds ratios, **CI:** Confidence intervals, **3CO:** 3-column osteotomy, **LOS:** Length of stay, **CCI:** Charlson Comorbidity Index, **PJF:** Proximal junctional failure

## INTRODUCTION

Scheuermann's kyphosis (SK) is a rigid structural deformity of the thoracic spine that was first described in 1920 by the Danish radiologist Holger Werfel Scheuermann (28). Scheuermann's kyphosis is defined as anterior wedging of ≥5° in at least three adjacent vertebral bodies and thoracic kyphosis of >45° (13,33). Endplate irregularities and Schmorl's nodes are frequently described in patients diagnosed with SK (5,13,21,27). SK affects both males and females (19), at a prevalence ranging from 0.4–10% (5,17,21,27). Conflicting reports on the overall incidence of this condition may be due to differences in the definition of SK, as the etiology of and genetic susceptibility

Martin HEEGAARD : 0000-0002-2566-4634
Tanvir Johanning BARI : 0000-0003-0513-7316
Søren OHRT-NISSEN : 0000-0002-8234-9948
Martin GEHRCHEN : 0000-0001-5523-2763

to this disease remain poorly understood (4,5,13,21,27). Non-surgical approaches are typically the treatment of choice for patients with SK. Surgical indications include kyphosis >70°, curve progression despite bracing, severe persistent pain, and/or neurologic deficits (24). Surgical procedures are aimed at improving the patient's health-related quality of life by correcting the deformity, reducing pain, and preventing further curve progression (6,16,34). Proximal junctional kyphosis (PJK) is a frequent complication of this procedure that may ultimately require revision surgery (13). PJK is multifactorial in origin and has been associated with surgical, radiographic, and patient-specific risk factors (12).

The Roussouly classification was introduced to describe normal variations in the shape of the sagittal spine in asymptomatic individuals (25). The authors of this classification system recognized that pelvic morphology influences the sacral slope (SS) and also the extent and type of lumbar lordosis (LL). They initially proposed four spine types and later added a fifth type that included an anteverted pelvis (Figure 1) (14). The reproducibility of the Roussouly classification system has been assessed (1). Ohrt-Nissen et al. (20) hypothesized that the Roussouly spine type might have an impact on the results of surgery in patients with adolescent idiopathic scoliosis (AIS). Likewise, methods for correcting spinal deformities characteristic of adult spinal deformity (ASD) that were generated based on individual ideal Roussouly spine types resulted in significant reductions in post-operative mechanical complications (2,22,23,29,30). However, to the best of our knowledge, there are no published studies that address the impact of spine shape restoration based on this classification system in patients diagnosed with SK.

Here, we present a retrospective study of postoperative outcomes of patients who underwent surgery for SK. We describe changes in spinopelvic parameters based on the Roussouly classification, report severity and frequency of complications, and assess the associations between efforts to correct these deformities based on the Roussouly classification system and postoperative PJK.

## MATERIAL and METHODS

### Subjects

This study was approved by the Danish Data Protection Agency and the Danish Patient Safety Authority (30 Nov. 2018 R-21054762; 30 Nov. 2018 3-3013-2760/1). We retrospectively screened all patients who underwent surgical treatment for SK at a quaternary spine institute from January 1, 2010, through December 31, 2017. We excluded all patients with less than two years of follow-up. Electronic medical records were used to obtain demographic and surgical data. All patients underwent a one-stage, posterior, all-pedicle screw instrumentation procedure without adjuvant anterior release. The surgical procedure involved facetectomies at the fusion levels supplemented with Ponte osteotomies, typically at the apex region of the deformity, as well as insertion of segmental uniplanar low-profile pedicle screws to facilitate fixation (Figure 2). In specific cases, the surgical technique included a pedicle subtraction osteotomy (PSO) aimed at increasing LL.

### Radiographic Analysis

Standing sagittal radiographs taken preoperatively, immediately postoperatively, and at two-year follow-up were analyzed by a single observer using the KEOPS online image management system (SMAIO, Lyon, France) (18). Sagittal spinopelvic parameters calculated included pelvic incidence (PI), pelvic tilt (PT), SS, global lordosis, global kyphosis, the sagittal vertical axis (SVA), and PI minus LL (PI-LL). The Roussouly spine type was also determined; methods for assigning actual and ideal Roussouly spine types are

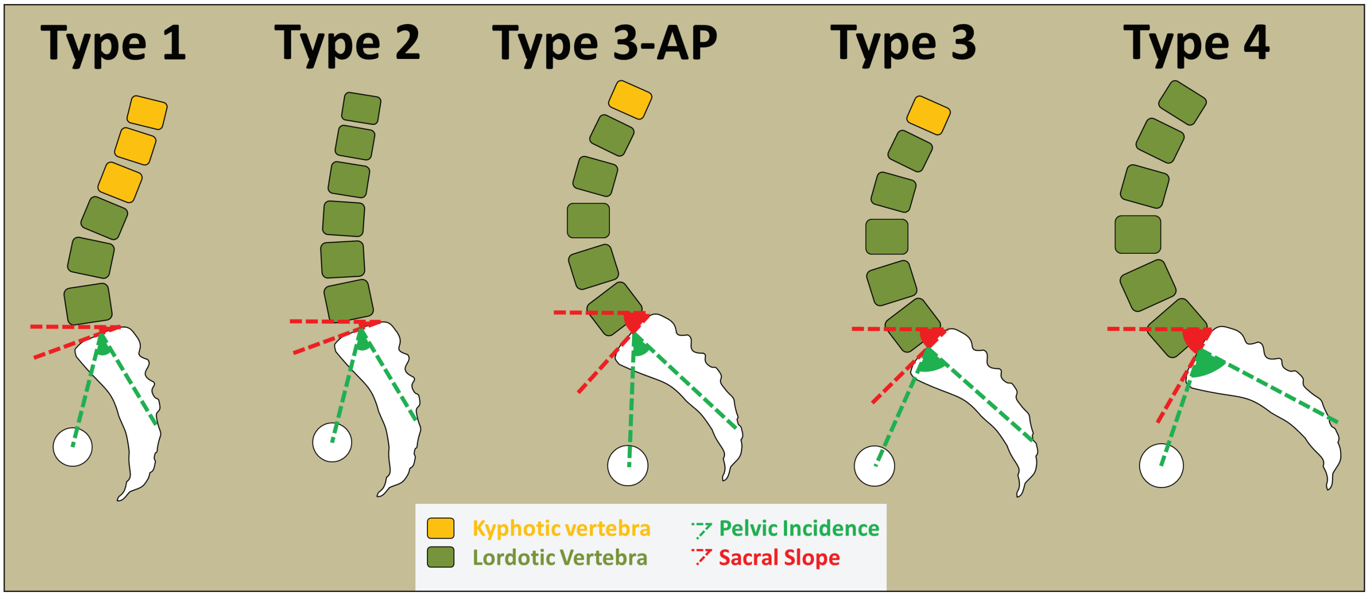


**Figure 1:** Illustration of the five modified Roussouly spine types. Further definition of these categories is provided in Figure 3.

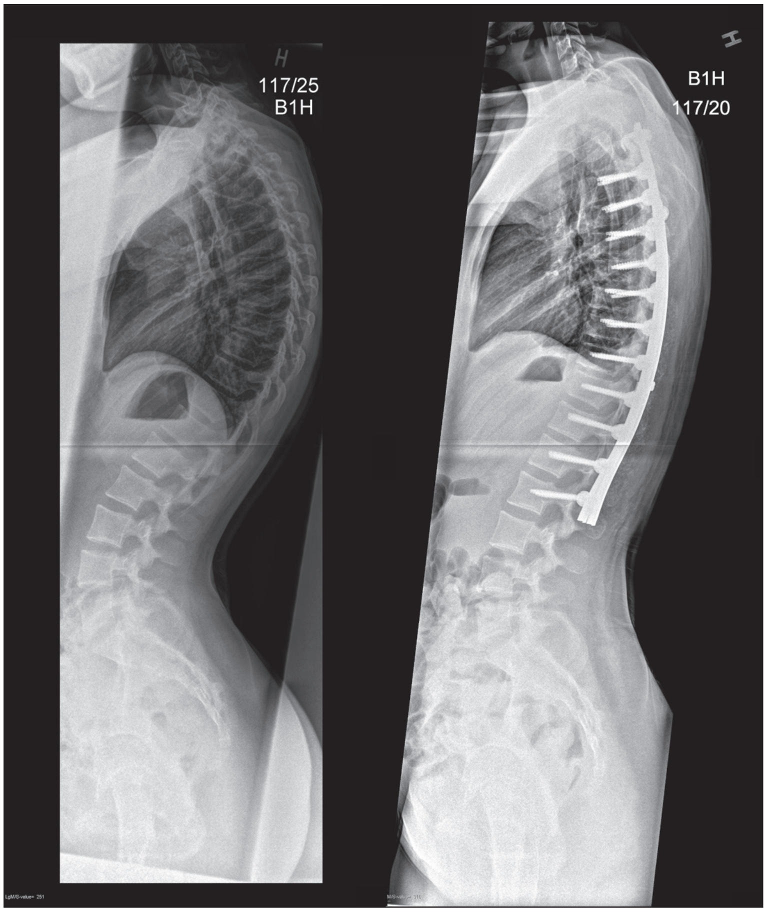


**Figure 2:** Long-standing, sagittal radiographs were taken preoperatively and in the immediate postoperative period. Shown are radiographs of the spine of a 18-year-old female at the time of surgery for Scheuermann's kyphosis (one-stage, posterior, all-pedicle screw instrumentation without adjuvant anterior release) with 12 instrumented levels (T3–L2) and 5.5 cobalt-chromium (CoCr) rods.

described in Figures 3 and 4, respectively. Patients were categorized as "restored" if the ideal Roussouly spine type was achieved postoperatively (Figure 4). All other patients were classified as "non-restored" (14,25).

### Complications

Electronic medical records were used to identify both medical and surgical postoperative complications. Complications were categorized as early (within 6 weeks) or late, as well as minor or major, the latter including a prolonged hospital length of stay (LOS), the need for additional invasive procedures, and/or death. The records also permitted us to identify mechanical complications, such as PJK, rod breakage, among others. PJK was defined as an increase in the kyphotic angle between the upper instrumented vertebrae (UIV) and the two vertebrae just above the UIV (UIV+2) of 10° or more (8,26). Other mechanical complications included screw breakage, loosening, or pull-out, as well as set-screw dislodgement (10).

### Statistical Analysis

All statistical analyses were performed using the language and environment R version 3.5.2 (R Development Core Team, 2011, Vienna, Austria). Data were reported as percentages (%), means with standard deviations (SDs), or medians with interquartile ranges (IQRs). Data distributions were evaluated using histograms. Two-tailed paired *t*-tests were performed to compare continuous data, and categorical variables were compared using Fisher's exact test. Predictors of PJK were assessed using logistic regression analysis and reported as odds ratios (ORs) with 95% confidence intervals (CIs).

## RESULTS

Our initial review of the electronic medical records identified 27 patients who had undergone spinal surgery for SK. Five of these cases (19%) were excluded due to the absence of a two-year radiographic follow-up. The remaining 22 patients with a median age of 23 (IQR, 20.0–43.9) years were included in the final analyses. The final patient cohort included eight (36%) females with a mean of 10.8 ± 2.2 instrumented levels. The mean follow-up time was 34.0 ± 13.4 months. Three-column osteotomies (3COs) were performed in seven (32%) of the patients. The median LOS was 7.0 (IQR, 6.0–8.8) days and the median Charlson Comorbidity Index (CCI) was 0.0 (IQR, 0.0–0.8). Three patients (14%) had a history of previous spine surgery and two patients (9%) had undergone previous instrumentation of ≥4 vertebrae. Table I describes patient characteristics categorized as restored or non-restored according to the Roussouly classification. There were no significant differences between groups with respect to the aforementioned parameters.

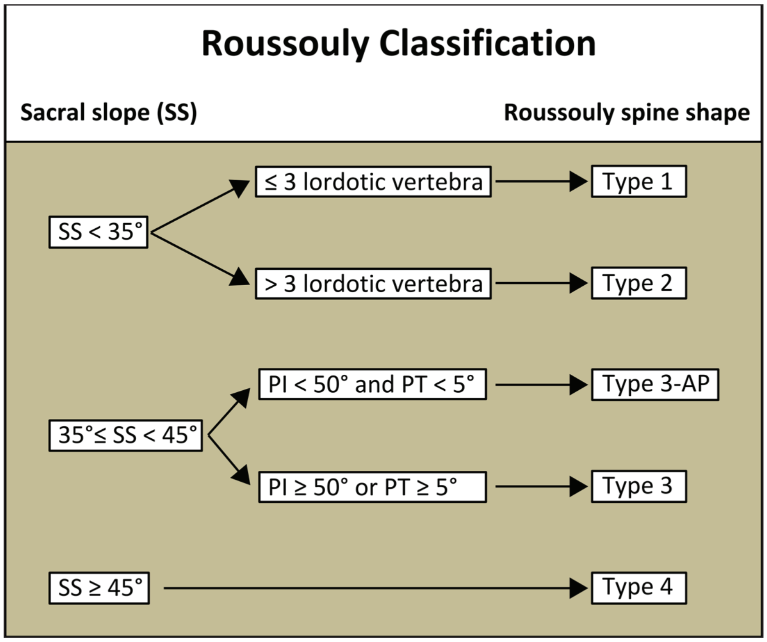


**Figure 3:** The Roussouly classification system is based on spinopelvic radiographic parameters and the number of lordotic vertebrae. (**PI:** Pelvic incidence, **PT:** Pelvic tilt, **3-AP:** 3-anteverted pelvis).

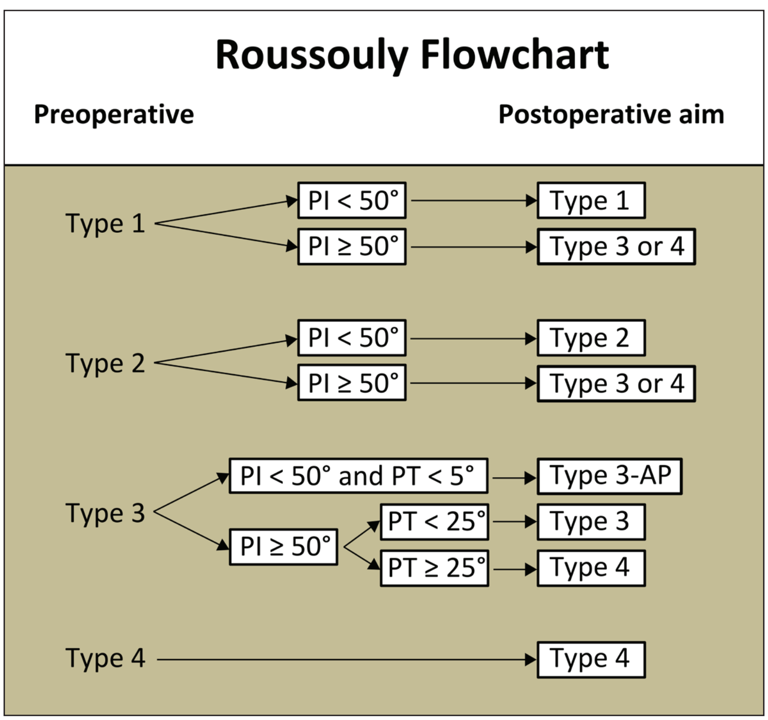


**Figure 4:** The flow chart illustrates how the ideal Roussouly spine type is calculated based on the preoperative shape and primarily pelvic incidence (PI). Of note, the postoperative goal for patients with a preoperative Type 2 spine and PI of 70 degrees should be a Roussouly type 3 or 4. (**PI:** Pelvic incidence, **PT:** Pelvic tilt; **3-AP:** 3-anteverted pelvis).

A comparison of pre- and postoperative spinopelvic parameters is presented in Table II. We identified a significant decrease in global lordosis (18.3 ± 18.0°) and global kyphosis (21.0 ± 17.1°) after the surgical procedure. PI-LL increased significantly by 20.3 ±19.5° (i.e., from 29.0 ± 19.5° preoperatively to -8.7 ± 14.6° postoperatively). PT also increased significantly with a mean of 4.1 ± 8.9°. We observed increases in SVA with a mean of 18.1° ± 44.1°, although this finding did not achieve statistical significance (p=0.067). We identified no significant pre- versus postoperative differences in these distributions based on the Roussouly classification (p=1.000).

Table III documents the postoperative complications that developed in the restored and non-restored patient groups. Overall, medical and surgical postoperative complications were reported in 17 (77%) of the original 22 patients. Nine (41%) of these patients developed early complications, while 16 (73%) experienced late complications. There were no significant differences in the incidence of early *versus*

**Table I:** Patient Characteristics of All 22 Patients by Groups of "Non-Restored" and "Restored" according to the Roussouly Classification

| Variable | Non-restored (n=6) | Restored (n=16) | Total (n=22) | p |
|---|---|---|---|---|
| Age (years (median[IQR])) | 23.0 [18.0, 38.0] | 23.0 [20.0, 44.5] | 23.0 [20.0, 43.8] | 0.825 |
| Sex (Female) | 2 (33.3%) | 6 (37.5%) | 8 (36.4%) | 1.000 |
| Instrumented levels | 11.5 (1.6) | 10.4 (2.3) | 10.7 (2.2) | 0.276 |
| Follow-up (Months) | 30.3 (15.0) | 35.4 (13.0) | 34.0 (13.4) | 0.437 |
| 3-Column Osteotomy | 4 (66.7%) | 3 (18.8%) | 7 (31.8%) | 0.102 |
| CCI (median[IQR]) | 0.0 [0.0, 0.8] | 0.0 [0.0, 0.2] | 0.0 [0.0, 0.8] | 0.638 |
| LOS (days (median[IQR])) | 6.0 [6.0, 8.2] | 7.0 [6.0, 8.2] | 7.0 [6.0, 8.8] | 0.524 |
| Previous spine surgery | 1 (16.7%) | 2 (12.5%) | 3 (13.6%) | 1.000 |
| Previous instrumented surgery* | 1 (16.7%) | 1 (6.2%) | 2 (9.1%) | 1.000 |

*Data are mean (standard deviation) or no. (%) unless otherwise specified.*
**≥ 4 vertebrae.*
***CCI:** Carlson Comorbidity Index, **LOS:** Length of stay, **IQR:** Interquartile range.*

**Table II:** Pre- and Postoperative Radiographic Parameters

| Variable | Pre-operative | Post-operative | Surgical correction | p |
|---|---|---|---|---|
| Pelvic Incidence | 44.2 (12.4) | 47.0 (13.3) | 2.8 (7.6) | 0.101 |
| Pelvic Tilt | 11.6 (9.8) | 15.7 (11.7) | 4.1 (8.9) | **0.043*** |
| Sacral Slope | 32.6 (11.2) | 31.4 (9.2) | -1.2 (4.9) | 0.271 |
| Global Lordosis** | 73.9 (18.2) | 55.6 (12.6) | -18.3 (18.0) | **<0.001*** |
| Global Kyphosis*** | 85.5 (17.3) | 64.6 (13.7) | -21.0 (17.1) | **<0.001*** |
| SVA | -10.8 (52.3) | 7.3 (51.0) | 18.1 (44.1) | 0.067 |
| Barrey ratio | 68.1 (438.8) | -58.0 (210.6) | -126.0 (548.3) | 0.293 |
| PI-LL | -29.0 (19.5) | -8.7 (14.6) | 20.3 (19.5) | **<0.001*** |
| Roussouly Classification | - | - | - | 1.000 |
| Type 1 | 0 (0%) | 0 (0%) | - | - |
| Type 2 | 13 (59.1%) | 14 (63.6%) | - | - |
| Type 3 | 2 (9.1%) | 3 (13.6%) | - | - |
| Type 3-AP | 4 (18.2%) | 3 (13.6%) | - | - |
| Type 4 | 3 (13.6%) | 2 (9.1%) | - | - |

*Data are mean (standard deviation) or counts (%) unless otherwise specified.*
** Indicates p-value under 0.05.*
*** Global Lordosis was calculated as the largest lordotic angle between any two vertebras.*
**** Global Kyphosis was calculated as the largest kyphotic angle between any two vertebras.*
***SVA:** Sagittal vertical axis, **PI-LL:** Pelvic incidence minus lumbar lordosis, **IQR:** Interquartile range, **3-AP:** 3-anteverted pelvis.*

late complications when comparing the restored to the non-restored group (p=1.000 and p=0.634, respectively). Furthermore, we found that 17 (77%) of the original 22 patients developed minor complications; seven patients (32%) developed major complications. As above, we identified no significant differences when comparing outcomes of the restored *versus* the non-restored patient groups. Fifteen patients (68%) developed mechanical complications. Twelve patients (55%) developed PJK, which is the most common mechanical complication, representing 80% of all mechanical complications reported. Interestingly, PJK was identified in five patients (83%) in the non-restored group compared to only

**Table III:** Postoperative Complications by Groups of "Non-Restored" and "Restored" according to the Roussouly Classification

| | Non-restored (n=6) | Restored (n=16) | Total (n=22) | p |
|---|---|---|---|---|
| Complications | 5 (83.3%) | 12 (75.0%) | 17 (77.3%) | 1.000 |
| Early complication | 2 (33.3%) | 7 (43.8%) | 9 (40.9%) | 1.000 |
| Early complications per patient (no.) | - | - | - | 1.000 |
| 1 | 2 (33.3%) | 6 (37.5%) | 8 (36.4%) | - |
| 2 | 0 (0.0%) | 1 (6.2%) | 1 (4.5%) | - |
| Late complication | 5 (83.3%) | 11 (68.8%) | 16 (72.7%) | 0.634 |
| Late complications per patient (no.) | - | - | - | 1.000 |
| 1 | 4 (66.7%) | 9 (56.2%) | 13 (59.1%) | - |
| 2 | 1 (16.7%) | 2 (12.5%) | 3 (13.6%) | - |
| Minor complication | 5 (83.3%) | 12 (75.0%) | 17 (77.3%) | 1.000 |
| Minor complications per patient (no.) | - | - | - | 1.000 |
| 1 | 3 (50.0%) | 8 (50.0%) | 11 (50.0%) | - |
| 2 | 2 (33.3%) | 4 (25.0%) | 6 (27.3%) | - |
| Major complication | 1 (16.7%) | 6 (37.5%) | 7 (31.8%) | 0.616 |
| Major complications per patient (no.) | - | - | - | 0.726 |
| 1 | 1 (16.7%) | 5 (31.2%) | 6 (27.3%) | - |
| 2 | 0 (0%) | 0 (0%) | 0 (0%) | - |
| 3 | 0 (0.0%) | 1 (6.2%) | 1 (4.5%) | - |
| Any mechanical complication (no.) | 5 (83.3%) | 10 (62.5%) | 15 (68.2%) | 0.616 |
| Proximal junctional kyphosis | 5 (83.3%) | 7 (43.8%) | 12 (54.5%) | 0.162 |
| Rod breakage | 0 (0.0%) | 1 (6.2%) | 1 (4.5%) | 1.000 |
| Other | 1 (16.7%) | 3 (18.8%) | 4 (18.2%) | 1.000 |

*Data are mean with standard deviation (SD) or counts with percentages (%).*
*If the postoperative Roussouly type was not in accordance to the proposed Roussouly type patients were categorized as "non-restored" and otherwise as "restored".*

seven patients (44%) in the restored group (p=0.162; Figure 5). The two-year revision rate due to mechanical complications was 18%. Seven patients (32%) underwent a 3CO procedure (PSO). All seven of these patients exhibited at least one minor complication; five patients (71%) developed PJK and three (43%) developed major complications that required revision surgery. The seven patients who underwent PSO procedures were evenly distributed with respect to Roussouly restoration, including three (43%) in the restored group and four (57%) in the non-restored group. Finally, the impact of radiographic parameters on the incidence of PJK was assessed using logistic regression analysis (Table IV). Non-restored patients exhibited increased odds of developing PJK in both uni- and multivariable models (OR, 6.43; 95% CI, 0.60–68.31 and OR, 9.39; 95% CI, 0.72–122.53, respectively). However, these differences did not achieve statistical significance (p=0.123 and p=0.087, respectively).

## DISCUSSION

In this study, we described specific changes in radiographic parameters in 22 patients who underwent SK surgery. We reported the incidence of postoperative complications and assessed the correlations between the development of postoperative PJK and the extent of correction of the surgical deformity as per the Roussouly classification system.

### Radiographic Parameters

Our findings are consistent with previous reports of surgical correction of spinopelvic radiographic parameters (27) and preoperative distribution of Roussouly classifications (14,20).

### Complications

We report a considerable complication rate (77%) following SK surgery compared to those reported in previous studies (3,11,17). For example, Lonner et al. (17) reported a major

**Table IV:** Predictors of Proximal Junctional Kyphosis Using Logistic Regressions Analysis

| | Univariable OR [CI 95] | p | Multivariable OR [CI 95] | p |
|---|---|---|---|---|
| Roussouly "non-restored"* | 6.43 [0.60;68.31] | 0.123 | 9.39 [0.72;122.53] | 0.087 |
| Age | 0.98 [0.94;1.03] | 0.492 | 0.99 [0.93;1.06] | 0.868 |
| Sex (Female) | 0.75 [0.13;4.29] | 0.746 | 0.87 [0.12;6.49] | 0.896 |
| Previous Spine Surgery | 0.36 [0.03;4.74] | 0.505 | 0.28 [0.00;20.34] | 0.559 |
| Preoperative Global Kyphosis** | 1.03 [0.98;1.09] | 0.287 | 1.04 [0.97;1.12] | 0.286 |
| Preoperative SVA | 1.00 [0.98;1.02] | 0.915 | 1.01 [0.98;1.04] | 0.518 |

*Data are odds ratio with 95% confidence interval [CI 95].*
** Non-restored, according to the Roussouly classification. See Figure 4 for full definition.*
*** Global Kyphosis was calculated as the largest kyphotic angle between any two vertebras.*
***SVA:** Sagittal Vertical Axis.*

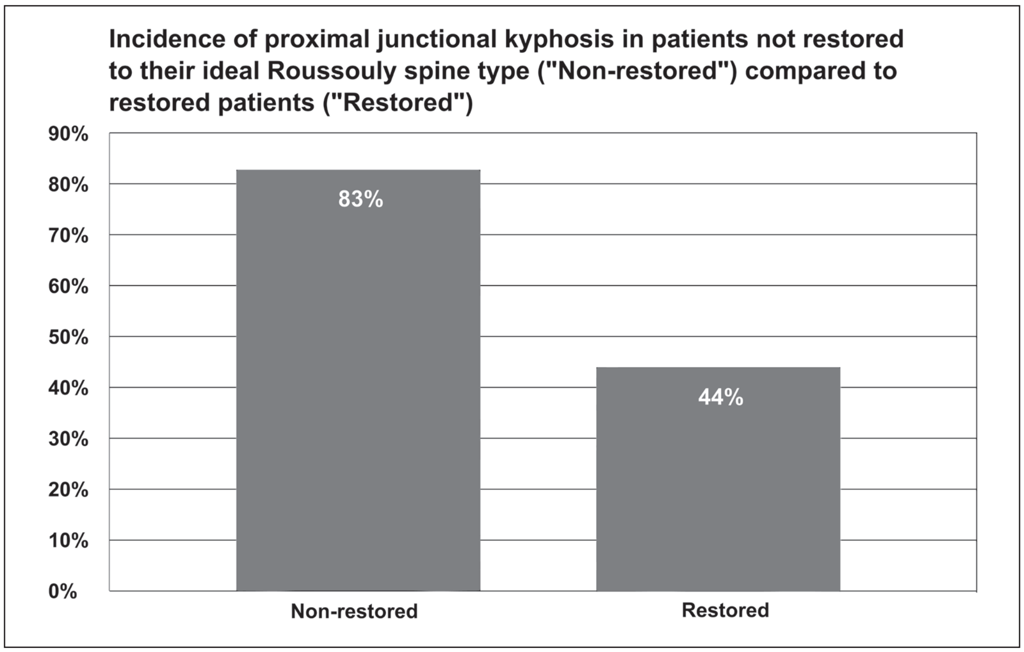


**Figure 5:** Bar plot documenting the incidence of postoperative PJK in both the restored and non-restored patient groups as defined by the Roussouly classification system. The incidence of PJK was greater in the non-restored group, although this difference did not achieve statistical significance. Patients were categorized retrospectively into restored and non-restored groups based on whether the postoperative Roussouly type did or did not match the ideal Roussouly spine type based on the flowchart shown in Figure 4. Data are presented as percentages (%), p=0.162. **PJK:** proximal junctional kyphosis.

complication rate of 16% in a series of 97 patients who underwent SK surgery; no minor complications were reported. We decided to include minor complications in this study so as to present a more accurate representation of these potential outcomes, notably because PJK does not always require further intervention. Here we defined PJK based solely on the radiographic assessment as previously described by Glattes et al. (8). One can argue that PJK is only of relevance when accompanied by an additional complication, such as fracture of the UIV (i.e., proximal junctional failure, PJF). However, because SK is seldom treated surgically, and we have only a small cohort of patient samples, we chose to include patients with any type of PJK in our analysis.

Our study also revealed an increased incidence of major complications (32%) compared to findings published in the aforementioned report by Lonner et al. (17). This difference may be largely due to disparities inherent in the definition of major complications. In a prospective study of 291 patients undergoing surgery for ASDs, Smith et al. (32) used a similar definition of complications and reported a similar rate of total complications (70% *versus* 77% shown here). However, we recognize that their study featured patients undergoing surgery for ASD as opposed to SK, which precludes direct comparisons to our work.

### Proximal Junctional Kyphosis (PJK)

This study provides insight into the association between PJK and sagittal balance based on the restoration of an ideal Roussouly spine type. PJK was previously reported in 24–53% (9,15,16,31) of patients who underwent SK surgery and reached 55% in the current study. These discrepancies might be ascribed to differences in the definition and diagnosis of PJK. Lonner et al. (15,16) defined PJK as the angle between the UIV and the first superior endplate level cephalad to the UIV

(UIV+1). By contrast, our definition of PJK extends from UIV to UIV+2 as proposed in 2005 by Glattes et al. (8,26). Glattes et al. (8) reported a 26% incidence of PJK in patients undergoing SK surgery using a definition of this complication that was similar to ours. Differences in diagnostic modalities, patient selection, and surgical techniques may also influence the rate of complications. Graat et al. (9) reported a 53% incidence of PJK using a definition that was similar to the one used in the current study. However, despite these similarities, there were numerous disparities with respect to our study. In the Graat et al. (9) study, the procedures were performed during the 1991–1998 time period; most of the patients underwent combined anterior-posterior surgery and were followed for as long as 21 years with concomitant increases in PJK throughout. By contrast, our study featured a posterior-only approach. Furthermore, we found that PJK may develop more frequently in patients who were not restored to their ideal Roussouly spine type. Although this difference did not achieve a statistical difference, our findings suggested a trend towards a higher incidence of PJK in the non-restored patient group. In recent years, the concept of restoring an ideal spine shape as per the Roussouly spine type has been proposed for patients with ASDs; the use of this algorithm correlated significantly with a reduced incidence of mechanical complications (22,23,29). We recognize that applying these criteria to SK patients, who as a group exhibit primarily thoracic spine deformities, may seem to be counterintuitive, as the Roussouly classification system focuses mainly on the lumbar spine and the spinopelvic parameters. However, the lumbar spine is frequently affected in SK due to compensatory increases in global lordosis that compensate for the increased kyphosis observed in these patients. The Roussouly classification describes an ideal shape of the sagittal spine based on the intrinsic connections between the thoracic, lumbar, and spinopelvic areas. This might explain the trend towards the reduced incidence of mechanical complications in the restored group (Figure 5). Future studies with larger patient cohorts may provide more conclusive results.

### Restoration of Roussouly Spine Type

Surgical correction of SK often focuses on defects in the mid-thoracic spine with little attention paid to sagittal spinopelvic parameters (i.e., PI, PT, and SS) (7,16). The Roussouly classification system is based primarily on the slope of the sacral endplate and the distribution of LL (14,25). Consequently, one might assume that individual Roussouly spine types would not be significantly affected by surgical treatment of SK when compared to those diagnosed with degenerative ASD (30). In the current study, our findings revealed no significant differences in the distribution of Roussouly classifications either before and after SK surgery. However, although the overall distribution was not affected, we did record changes in Roussouly classification in many patients. There are two possible explanations for these observations. First, changes in one patient may be balanced by concurrent changes in another patient which will yield an overall unchanged distribution. As a second explanation, we note that although 73% of patients exhibited an ideal postoperative spine shape according to the Roussouly classification, in most of these cases, the proposed ideal postoperative spine type was the same as that exhibited preoperatively. Taken together, these observations suggest that most patients undergoing SK surgery do not require surgical adjustment focused on correcting the Roussouly spine type. However, there are cases in which a proposed spine type was not achieved postoperatively, either due to an unintentional change in an already balanced spine (i.e., overcorrection of kyphosis), or an imbalanced spine that was not properly corrected. Under these circumstances (represented by the non-restored group) we found that PJK developed almost twice as frequently compared to patients who were restored to their ideal spine shape, although the difference did not reach statistical significance. Additionally, of the six patients assigned to the non-restored group, four (67%) underwent PSO surgery, and all developed minor complications (PJK); one patient (25%) also developed an implant failure that required surgical revision. One could argue that the PSO procedure drives the elevated rate of PJK in the non-restored group. This is particularly notable, given that PSO is often performed in cases with larger and more rigid deformities with known elevated surgical-associated risks. Interestingly, of the three patient cases assigned to the restored group who underwent the PSO procedure, only one (33%) developed postoperative PJK, compared to 100% observed among those in the non-restored group. Thus, our results suggest that failure to attain an ideal Roussouly spine type may be a major cause of PJK in this patient cohort. Further studies with larger numbers of patients undergoing the 3CO procedure will be needed to explore this hypothesis.

### Strengths and Limitations

This study is the first to assess the role of the Roussouly classification in patients diagnosed with SK. The single-center study design combined with a relatively short inclusion period facilitated homogeneity with respect to several critical variables, including surgical technique, surgeon-related differences, perioperative observation, postoperative treatment and care, assessment of postoperative complications, and follow-up modalities. However, we recognize that this study includes several limitations. The sample size was small and thus associated with the risks of both Type I and Type II errors. The eligibility ratio was 82%; we recognize that a certain amount of selection bias cannot be ruled out. However, we find this to be acceptable and perhaps unavoidable when assessing patients with SK, as surgery is performed only rarely for patients with this diagnosis. Furthermore, our institution also serves the population of the Faroe Islands and Greenland; follow-up of surgical treatment of these patients is provided at local centers. These patients will be recorded as "lost to follow-up" when in reality, they are re-referred to our center only if major postoperative complications develop. Thus, the true incidence of postoperative complications, including PJK, is probably lower than reported here. Finally, the inclusion period in this study was limited to eight years. Although this feature permits us to eliminate numerous modifiable variables, prolonged inclusion periods will be necessary to ensure sufficient sample sizes.

## CONCLUSION

Findings from our retrospective study of 22 patients undergoing surgery for SK revealed that 77% developed at least one medical or surgical complication and 32% exhibited major complications, with a two-year revision rate of 18%. PJK developed in 55% of the patients and was almost twice as frequent in patients who were not restored compared to those who were restored to their ideal Roussouly spine type. We propose further validation of these findings in larger patient cohorts.

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## AUTHORSHIP CONTRIBUTION

**Study conception and design:** MH, TJB, SON, MG

**Data collection:** MH

**Analysis and interpretation of results:** MH, TJB, SON, MG

**Draft manuscript preparation:** MH, TJB, SON

**Critical revision of the article:** MH, TJB, SON, MG

**Other (study supervision, fundings, materials, etc...):** MG

All authors (MH, TJB, SON, MG) reviewed the results and approved the final version of the manuscript.

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