SCHEUERMANN'S DISEASE SURGERY. MAJOR PROBLEMS

Non-systematic literature review (part II)

M.V. Mikhaylovskiy
Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia

Objective. To analyze literature data on the frequency of junctional kyphosis in surgery for Scheuermann's disease, its relationship with spinopelvic parameters, risk factors and prevention of its development.
Material and Methods. A search for sources in Scopus and Web of Science databases revealed 62 articles published from 1975 to 2021 and containing the required information. Of these, 56 publications meet the inclusion criteria.
Results. The selected 56 articles contain data on 2,110 patients. In total, 247 (11.8 %) cases of proximal junctional kyphosis were diagnosed, including 6 (0.3 %) cases of proximal junctional failure. The total number of distal junctional kyphosis cases was 124 (5.9 %). Forty-five reoperations were performed. Many potential risk factors have been identified in publications, but there is no consensus on any of them. As a result, there is no a well-founded common position on the prevention of junctional kyphosis development. Spinopelvic parameters in Scheuermann's disease are significantly less than those in the general population and do not tend to change after surgical correction of kyphosis. As for their relationship with the risk of development of proximal and distal junctional kyphosis, there is no consensus to date.
Conclusion. This review is the largest in terms of coverage of literary sources on the problem of the development of junctional kyphosis in surgery for Scheuermann's disease. The causes for the development of this complication remain unknown, hence there is the lack of generally accepted methods of prevention. New studies with long postoperative follow-up are needed.
Key Words: Scheuermann's disease, surgical treatment, proximal junctional kyphosis, distal junctional kyphosis.
Please cite this paper as: *Mikhaylovskiy MV. Scheuermann's disease surgery. Major problems: non-systematic literature review (part II). Hir. Pozvonoc. 2021;18(4):28–40. In Russian.*
DOI: http://dx.doi.org/10.14531/ss2021.4.28-40.

In the first part of the review (Spine Surgery. 2021. Vol. 18. No. 3. P. 6–18) the issues related to the choice of the surgical technique for the treatment of patients with Scheuermann's disease were discussed. It was about the advantages and disadvantages of one- and two-stage corrective interventions. Furthermore, one-stage intervention (posterior correction, spinal fusion) was advantageous for most parameters over two-stage anterior release, posterior correction, spinal fusion). The second equally important problem in the surgery of Scheuermann's disease is the abnormal changes in the spine in the sagittal plane at the upper and lower boundaries of the instrumented spinal fusion area, determined as junctional kyphosis.

The earliest paper devoted to the application results of effective endocorrectors (Harrington rods) in the treatment of Scheuermann's disease dates back to 1975 [1]. The authors noted a large number of complications. Nevertheless, the paper did not contain any information regarding junctional kyphosis. In the next article of the same group of authors [2], a considerable (more than 10°) loss of correction distal to the fusion area was reported; in five patients, the inferior terminal vertebra of the kyphotic curve was not included in the block. The complication was asymptomatic, but in one case a reoperation was necessary. The authors do not give any guidelines for determining the optimal length of the spinal fusion area.

Further, the number of papers focused on the problem of choosing the length of the instrumented spinal fusion area in the surgery of Scheuermann's disease increased. Very soon there was an understanding of the nature of complications associated with suboptimal planning of the procedure, which have obtained the definition of junctional kyphosis (PJK, DJK) formed at the upper and lower boundaries of the fusion zone. The fact that in the vast majority of cases these complications were asymptomatic did not lessen the attention to this issue. Quite the contrary: over time, it turned out that junctional kyphosis are not static condition. Their course may have negative changes [3]. The frequency of junctional kyphosis is generally considered to be high, but extremely variable – from 0 to 70 % [4, 5]. Many attempts have been made to define risk factors for their development and to design prevention techniques. A connection was found between the development of junctional kyphosis and indicators of spinal and pelvic parameters. Meanwhile, there are very few reviews regarding all aspects of the problem that have focused the available data as fully as possible [6–8].

Objective: to analyze literature data on the frequency of junctional kyphosis in surgery for Scheuermann's disease, its relationship with spinopelvic parameters, risk factors and prevention of its development.

Material and Methods

A search for sources in Scopus and Web of Science databases revealed 62 articles published from 1975 to 2021 and containing the required information. It is thought that there are only a small number of papers capable of being useful outside this list.

Entry criterion: patients operated for severe kyphosis due to Scheuermann's disease, irrespective of age and type of vertebral instruments used. Exclusion criteria: the size of the investigated group is less than 10 people, the duration of postoperative follow-up is less than 24 months. Out of 62 publications, 56 met these criteria [1–5, 11–14, 16–62].

Abbreviations and definitions used:

1. TK (thoracic kyphosis) is the Cobb angle of the kyphotic curve from the cranial endplate of T4 to the caudal endplate of T12.

2. LL (lumbar lordosis) is the Cobb angle of lumbar lordosis from the cranial endplate of L1 to the endplate of S1.

3. PJA – proximal junctional angle; Cobb angle between the lines of the caudal endplate of the upper instrumented vertebra and the cranial endplate of the vertebra located two segments cranial to the upper instrumented vertebra [9].

4. PJK – proximal junctional kyphosis; the proximal junction angle is 10° or more and at least 10° greater than prior to surgery [9].

5. PJF (proximal junctional failure due to UIV or UIV + 1 fracture, displacement of the endocorrector at the level of UIV and/or sagittal subluxation) – PJK, followed by the development of severe kyphotic deformity, pain syndrome, cosmetic defect or neurologic impairment and requiring revision intervention [10].

6. DJA (distal junctional angle) is the angle between the cranial endplate of LIV and the caudal endplate of the lower adjacent vertebra [11].

7. DJK/DJF (distal junctional kyphosis/failure) – an increase in DGA by 10° or more and/or a displacement of the implant at the LIV level [10].

8. SSV (sagittal stable vertebra) is the most proximal vertebra, which is affected by a perpendicular raised from the posterosuperior angle of S1 [12].

9. FLD (first lordotic disc) is the most proximal lumbar intervertebral disc, whose endplates converge in the posterior direction [13].

10. FLV (first lordotic vertebra) is a vertebra located directly under the first lordotic disc.

11. SVA (sagittal vertical axis) is a vertical down from the center of C7 vertebra body in a profile spondylogram. The distance (in mm) from SVA to the posterior angle of S1 vertebra body characterizes the condition of sagittal balance, which is determined as negative (-) if the SVA passes dorsally to the posterosuperior angle of S1 vertebra body, or positive (+) if it is anterior [14].

12. UEV – upper end vertebra of the Cobb angle of the kyphotic curve.

13. LEV – low end vertebra of the Cobb angle of the kyphotic curve.

14. UIV – upper instrumented vertebra.

15. LIV – low instrumented vertebra.

16. PI (pelvic incidence) is the angle formed by a line drawn through the center of the femoral heads to the middle of S1 endplate and a line perpendicular to this endplate (mean value 51–53°) [15].

17. PT (pelvic tilt) is the angle between the vertical line and the line drawn through the center of the femoral heads to the middle of S1 endplate (mean value 11.1–13.0°).

18. SS (sacral slope) is the angle between S1 endplate and the horizontal line (mean value is 39.6–41.7°).

Results

Incidence rate of junctional kyphosis. The Table includes data from 56 publications on the outcomes of surgical correction of juvenile kyphosis. These papers contain data allowing to determine their incidence rate. We thought it would be useful to include in the Table, among other things, data from publications which do not mention the incidence of junctional kyphosis. The authors of these papers either did not face the development of complications, or did not feel it necessary to mention such cases. Anyway, we believe that the inclusion of this data (first of all, the number of operated patients) is justified, since it enhances the reliability of the analysis as a whole.

Quantitative analysis of the information collected in the Table showed the following. Fifty six papers on the outcomes of kyphosis correction due to Scheuermann's disease have data on 2,110 patients, which means that the average study group consisted of 38 people. The duration of postoperative follow-up ranged from 24 to 216 months. The total number of diagnosed PJK was 247 (11.8 % of the total number of patients), including 6 (0.3 %) cases of PJF. The overall amount of DJK was 124 (5.9 % of the total number of patients). Totally, the authors of the published articles had to perform 45 reoperations due to the development of clinically significant junctional kyphosis.

Risk factors for junctional kyphosis. Since the mid-70s of the twentieth century, many surgeons have thought it essential to express their thoughts regarding the optimal length of spinal fusion area in kyphosis correction associated with Scheuermann's disease.

Taylor et al. [16], who used Harrington rods, believed that anchor points (hooks) were required as much as possible, especially on the apex. They suggested that all the vertebrae of the preoperative curve should be included in the block area, i.e., at least from T3 to T12 or even more. This is the only way to reach a smooth transition from thoracic kyphosis to lumbar lordosis and obtain a cosmetic fix, which is most important for the patient. Herndon et al. [17] was of the same opinion, who emphasized that the spinal fusion should capture all the wedge-shaped vertebrae and go beyond their area. It is also essential to block the entire anterior release area from behind. A similar strategy was recommended by Sturm et al. [24]. According to Reinhardt et al. [23], the spinal fusion area should contain not only the entire kyphosis with end vertebrae, but likewise the next square vertebra (the vertebral body has no wedge shape) not included in the kyphosis. This promotes a smooth tran-

sition to the lumbar spine. As far as we can see, the term "junctional kyphosis" was originally given in this paper.

It was probably Lowe and Kasten [13] who were the first to rely on clear definitions of junctional kyphosis in their findings and guidelines. They measured PJK from the upper endplate of the upper instrumented vertebra to the most kyphotic vertebra cranially. Risk factors for PJK development: correction of more than 50 % of the arch, non-inclusion in the UEV block. DJK was defined from the lower plate of LIV to the lower plate of the kyphotic lumbar vertebra itself at the bottom. Risk factor: non-inclusion in the FLD block. Inclusion of only the lower end vertebra of the curve is not sufficient for DJK prevention. DJK is not related to kyphosis hypercorrection. It is essential to keep the ligaments of the spine above and below the block zone.

Ascani and Rosa [63] suggested extending the block zone by one additional segment into the zone of the lower neutral vertebra, invariably including L1 vertebra in it.

Papageloupulos et al. [27] considered the following as possible risk factors: osteoporosis, too short spinal fusion due to incorrect determination of the end vertebra, damaged ligamentous apparatus (supra-, intra-articular, posterior longitudinal ligaments), kyphosis hypercorrection, application only of lever correction (also associated with ligament dissection). In their opinion, even with the correctly chosen block length, the concentration of dorsal distraction actions at both block ends can result in angulation.

According to Lim et al. [30], the optimal level of UIV is T2; the magnitude of correction received is not a risk factor for junctional kyphosis. On the contrary, Herrera-Soto et al. [33] believed that correction to a kyphosis magnitude of less than 40° and more than 50 % of its initial value is undesirable. It is required to instrument all levels of the anterior release and block the entire kyphosis length, i.e., from the UEV to the vertebra distal to FLD.

Arun et al. [36] recommended to block the T2–L2 level for kyphosis greater than 70°. They noted that there was no PJK at the upper boundary of the block at T2 level. Modern instrumentation and a block from T2 to FLD enable to correct kyphosis to normal parameters. The problem of hypercorrection does not arise. Nevertheless, with a BMI of more than 25, the risk of developing DJK is enhanced.

According to Lee et al. [37], the optimal proximal boundary of the block zone is the vertebra, which is transitional between the thoracic and cervical spine; the distal border is the most proximal vertebra touching the SVA in the standing position, and it is advisable to include it in the FLD block.

Geck et al. [38] determined the proximal border of the spinal fusion area based on the selection of a normally aligned segment of the thoracic spine. The distal border is the first vertebra below the FLD.

Lonner et al. [14] emphasized that the development of PJK is associated with a large magnitude of kyphosis initially and at the end of the follow-up period, when the correction was moderate. The upper boundary of the zone at the UEV level or cranial indicates a reduced risk of PJK. There was no correlation between the type of upper grip (hooks, screws) and junctional kyphosis. Risk factor for the development of DJK is LIV at the level of the lower end vertebra. In all patients with DJK, the lower instrumented vertebra was located proximal to SSV.

According to Denis et al. [39], the main reasons for PJK are non-inclusion in the UEV block, injury to ligamentum flavum in the transition zone, or both of these factors. The extent of kyphosis and the magnitude of its correction do not matter. Meanwhile, if we consider the correction magnitude separately (more or less than 50 % of the curve magnitude), there will be a difference – 52 % versus 20 %, respectively. However, these data lose their significance when considering cases of non-inclusion in the UIV block or injury to ligamentum flavum. The ligamentum flavum should be completely preserved. Implantation of a laminar hook or a sublaminar wire at the UIV level can cause complications even if the block boundary is correctly selected. DJK prevention is the inclusion of the first lordotic disc (FLD) in the block.

The authors describe the best fit line technique, which, when choosing a UIV, allows overcoming the challenge of poor visualization of the upper thoracic vertebrae. The approach is based on identification of the edges of the anterior and posterior endplates in the visible zone of the lower cervical and upper thoracic spine. Lines are drawn between these zones, and the perpendicular to the lines indicates the upper instrumented vertebra.

Cho et al. [12] suggested a technique for selecting LIV based on the definition of SSV to obtain a balanced and stable spine. Incorrect planning of the boundaries of the kyphosis zone breaks the overall sagittal balance and enhances the risk of junctional kyphosis. The authors draw upon King's theory: a stable vertebra should be the most distal blocked vertebra in idiopathic thoracic scoliosis. The overall sagittal balance after procedure becomes more negative. Posterior fusion shifts the rotation axis of the middle column dorsally from the center of gravity in the sagittal plane. For maintaining sagittal balance after surgery, both ends of the fusion area should be located within the gravity center. Consequently, the distal end should be at SSV level, and the proximal end should be at the level of the upper end vertebra of the curve. The authors pointed out that the use of SSV allows to downgrade the negative spine balance. If the block area is shorter than before SSV, the distal end of the block is located dorsally to the sacrum. The negative sagittal balance is alleviated by DJK development. The authors suggest that DJK is a more significant problem than PJK, due to the more frequent and pronounced pain syndrome.

Koptan et al. [4] used an instrumentation system where all anchors were pedicular screws. They mentioned considerable advantages of this technique, including only a single case of junctional kyphosis.

If there is an anterior sagittal imbalance, Ning et al. [41] assumed that UIV should correspond to UEV or T2. LIV

Table

Incidence of junctional kyphosis after surgical correction of spinal deformities due to Scheuermann's disease (literature data)

Authors	Year	Patients, n	Follow-up period, months	PJK, n (%)	DJK, n (%)	Reoperations, n
Bradford et al. [1]	1975	22	–	–	–	5
Taylor et al. [16]	1979	23	28	–	1 (4.3)*	–
Bradford et al. [2]	1980	24	24–68	1 (4.2)*	4 (16.7)*	1
Herndon et al. [17]	1981	13	29	–	3(23.0)*	–
Heine et al. [18]	1984	11	39	–	–	–
Nerubay, Katznelson[19]	1986	14	18–72	2 (14.3)*	–	2
Speck, Chopin [20]	1986	59	56	5 (8.5)*	2 (3.4)*	2
Lowe et al. [21]	1987	24	32	–	2(8.3)	2
Otsuka et al. [22]	1990	10	27	3 (30.0)	–	–
Reinhardt, Bassett [23]	1990	14	–	5 (35.7)	1 (7.1)	–
Sturm et al. [24]	1993	39	72	1 (2.6)	–	–
Lowe, Kasten[13]	1994	32	42	10 (32.2)	9 (28.1)	–
Ferreira-Alvez et al. [25]	1995	38	60	–	–	–
Gennari et al. [26]	1997	15	48	–	–	–
Papagelopoulos et al. [27]	2001	14	54–72	1 (7.1)	1 (7.1)	–
Poolman et al. [28]	2002	23	75	3 (13.0)	–	–
Hosman et al. [29]	2002	33	42	1 (3.0)	–	–
Lim et al. [30]	2004	23	38	3 (13.0)	–	–
Yang et al.[31]	2004	16	–	–	–	–
Atici et al. [32]	2004	10	60	2 (20.0)	–	–
Herrera-Soto et al. [33]	2005	19	32	–	–	–
Johnston et al. [34]	2005	27	30	–	–	–
Metz-Stavenhagen et al. [35]	2006	55	75	3 (5.4)	–	–
Arun et al. [36]	2006	15	60–70	–	3 (20.0)	–
Lee et al. [37]	2006	39	32–67	2 (5.1)	1 (2.6)	2
Lonner et al. [14]	2007	78	29–39	25 (32.1)	4 (5.1)	4
Geck et al. [38]	2007	17	24	1 (5.9)	1 (5.9)	–
Denis et al. [39]	2009	67	70	20 (29.8)	8 (11.9)	–
Cho et al. [12]	2009	31	44	3 (9.7)	7 (22.6)	–
Koptan et al. [4]	2009	33	24	1 (3.0)	–	1
Tsutsui et al. [40]	2011	11	–	–	–	–
Ning et al. [41]	2011	86	24	28 (32.6)	11 (12.8)	–
Billgic et al. [42]	2012	12	38	–	–	–
Temponi et al. [43]	2011	28	37	–	1 (3.6)*	1
Koller et al. [44]	2014	111	24	–	2 (1.8)	–
Behrbalk et al. [45]	2014	21	24	1 (4.8)	–	1
Koller et al. [46]	2015	166	43–47	–	–	–
Nasto et al. [47]	2016	37	24	7 (18.9) (3 – PJF)	–	3
Etemadifar et al. [48]	2016	30	58	1 (3.3)	1 (3.3)	2
Mikhaylovskiy et al. [49]	2015	36	42	1 (2.8)	6 (16.7)	–
Yanic et al. [50]	2016	54	28	–	11 (20.4)	–
Yanic et al. [51]	2015	60	25	5 (8.3)	–	–
Faldini et al. [52]	2015	20	25	1 (5.0)	–	1
Kahraman et al. [53]	2016	28	88	–	–	–
Riouallon et al. [54]	2018	131	51	30 (2.3)	–	5
Graat et al. [3]	2016	29	216	15 (51.7)	–	–
Ghasemi et al. [11]	2017	40	48–72	–	6 (15.0)	–

End of the table

Authors	Year	Patients, n	Observation period, months	PJK, n (%)	DJK, n (%)	Reoperations, n
Cobden et al. [55]	2017	20	41	3 (15.0)	–	–
Kim et al. [56]	2017	44	37	6 (13.6)	5 (11.4)	–
Lonner et al. [57]	2018	96	24	23 (23.9)	–	–
Dikici et al. [58]	2018	39	92	–	12 (30.8)	2
Zhu et al. [59]	2018	44	24	8 (18.2)	3 (6.8)	–
Mirzashahi et al. [60]	2018	18	18	–	–	–
Hwang et al. [61]	2019	45	15	3 (6.7)	–	1
Zhu et al. [62]	2019	45	24	–	5 (11.1)	–
McDonnell et al. [5]	2020	31	34	23 (74.2) (3 – PJF)	14 (45.1)	10 (4 – PJF)
Total		2110	–	247 (11.8)	124 (5.9)	45

* The diagnosis is formulated according to the description of the clinical and radiological picture, since the authors of the article did not use the term "junctional kyphosis".

should be below FLD or at SSV level in case of global sagittal imbalance.

Tsutsui et al. [[40] considered that the most proximal vertebra should be chosen as LIV, which body is affected by the posterior sacral line and which is located below the FLD in the transition zone between kyphosis and lordosis. The choice of UIV is based on inclusion in UEV block.

Mikhaylovskiy et al. [49] and Dikici et al. [58] proved the validity of the choice of SSV as LIV.

Nasto et al. [47] believed it was crucial to preserve the spinous processes, supra- and inter-spinous ligaments of UIV and at a higher level to prevent the PJK development.

Yanic et al. [50] base their comprehension of the DJK problem on the DJA value. DJK is diagnosed if this disc has become neutral or kyphotic. They believe that in order to prevent DJK, there is no need to extend the spinal fusion area to SSV. It will be enough to FLV.

The same authors [51] suggested an original modification of the surgical technique –two threads of screws implanted in the UIV area are left outside the cortical bone. Meanwhile, the ligaments were always preserved, and the UEV was included in the block in all cases. The new technique renders the transition from rigid fixation to free-moving segments softer. The technique of lever reduction and tightening of nuts from the distal to the proximal level was applied. This also decreases the risk of top screws being pulled out.

According to Ghasemi et al. [11], large correction of thoracic kyphosis, the young age of the patient and the distance of the plumb line from the LIV dorsally from the sacrum were considered as risk factors for DJK development.

Graat et al. [3], who presented the surgical outcomes with long follow-up periods (18 years), noted an increase in PJK frequency over the years – from 31 to 53 %. In their opinion, the choice of UEV as a UIV does not give reliable advantages. Correction technique is also not essential; the integrity of joints and ligaments is crucial.

Kim et al. [56] considered that the choice of SSV as LIV in Scheuermann's disease is determined by the need to keep sagittal balance. Hyperkyphosis is compensated by cervical and lumbar hyperlordosis. This can cause an incorrect evaluation of truly lordotic discs, since an enhanced physiological lordosis results in lordosis of discs that are supposed to be parallel or even slightly kyphotic. It involves a suboptimal choice of LIV and a short spinal fusion area, which results in DJK development, screw displacement, decompensation and reoperation. The choice of SSV decreases the level of complications at the cost of immobilization of segments in young patients.

Zhu et al. [59] applied double rods, which reduced the frequency of PJK development (a more detailed description of the technique will be given below).

Kumar et al. [7] suggest to form surgical strategy in relation to PJK problem, based on the following provisions: 1) PJK is the result of too short or long instrumentation in children and adults; 2) it is required to determine UEV and apply the best fit line technique; 3) the ligamentum flavum must be preserved, a correction of more than 50 % is not a risk factor; 4) the proximal part of the rod should be bent to match kyphosis; 5) kyphosis correction should be in harmony with lordosis and sacral slope, although the exact ratios have not yet been established; 6) the patient and his family should be notified regarding the possibility of PJK and its consequences.

Riouallon et al. [54] consider that the frequency of PJK development is not associated with the number of surgical stages. An essential factor is the restoration of the spinal sagittal contour.

Gong et al. [8] submitted a meta-analysis confirming the advantages of choosing SSV as LIV in comparison with FLV.

Zhu et al. [62], considering kyphosis associated with Scheuermann's disease, assume, that the block zone in thoracolumbar deformity may be relatively short (up to FLV), preserving a larger number of free levels. In case of thoracic kyphosis,

the block should be extended to SSV. It will eliminate a lot of problems. If there is a thoracic kyphosis, the risk factor may be a large magnitude of kyphosis and the degree of its correction. If DJA was lordotic before the procedure but became neutral or kyphotic, this is also DJK.

Lonner et al. [57] have never noted DJK in the patients operated by them, although the rule of SSV inclusion was not observed. Probably, the reason for DJK absence is that the kyphosis apex migrated in the proximal direction, which could change SSV and FLD. The PJA value before and after in patients with and without PJK did not differ. Consequently, the upper thoracic sagittal contour is not a risk factor.

Hwang et al. [61] confirm that in the optimally selected spinal fusion area above and below the kyphosis apex there should be a symmetrical number of segments, and the disk above the hypothetical UIV should be lordosed.

Berjano et al. [64] suggest that to avoid the progression of kyphosis below the spinal fusion area, it is required to extend it distally by a segment into the zone of the lower neutral vertebra and always involve the L1 vertebra in it. Protective factors: resistance of the intervertebral discs to axial compression, resistance of the vertebral body tissue, resistance of the chest and abdominal cavity contents, dorsal ligament complex, and extensor muscles. Deforming factors: flexion moment of force, moment of force of body weight, traction of ventral muscles and ligaments, neurological and postural disorders, daily activity (sitting, bending), ventrally directed pressure efforts (patient care).

McDonnell et al. [5] point out that it is required to include UEV in the block. Two-stage intervention (anterior release, posterior correction) prevents the development of PJF better than one-stage (posterior correction).

It is easy to see that the opinions of numerous researchers, given above in chronological order, have contradictions in the choice of block zone length and prevention of junctional kyphosis.

Spinopelvic parameters. The discussion of junctional kyphosis is impossible in isolation from the issues related to the characteristics of the spinopelvic junction. Changes in the sagittal profile cause a disruption of trunk balance and increased metabolic costs for its preservation. This fully applies to Scheuermann's disease, since pathological changes in the shape of the vertebral column in juvenile kyphosis occur exactly in the sagittal plane (minimal scoliotic deviations have no practical significance). It is essential to consider at least three aspects of the problem: the value of the spinopelvic parameters in Scheuermann's disease, their dynamics in the postoperative period and the relationship with the development of junctional kyphosis.

In 2014, two studies were published on the values of the spinopelvic parameters in adolescents and adults suffering from Scheuermann's disease [65, 66]. Jiang et al. [65] compared two groups: 55 patients with Scheuermann's disease and 60 healthy adolescents. It turned out that PI and PT indicators in the group with Scheuermann's disease were significantly lower than in the group of healthy adolescents – 32° vs. 45° and 0.2° vs. 11.9°, respectively. Meanwhile, a negative PT indicator (the vertical line is located dorsally to the line connecting the center of the femoral heads and S1 endplate) in patients was revealed in 48.8 % of cases, and in healthy patients – only in 10.0 %. In turn, SS and the distance of SVA from the dorsal angle of S1 differed insignificantly in the two groups. As for the thoracic and thoracolumbar types of kyphosis, PI and PT in both cases were lower than in the control group. The SS value was considerably higher in thoracic kyphosis and in healthy adolescents.

PI is a key factor defining the pelvic location in space. It is strictly individual and does not depend on other parameters [67]; it tends to increase in childhood and adolescence and stabilizes at the age of final skeletal maturity [68]. In this regard, Jiang et al. [65] suggested that low PI values in young patients with Scheuermann's disease may be associated with the onset and progression of kyphosis at an early age. Fotiadis et al. [69] revealed higher height, weight and BMI in patients with Scheuermann's disease, which points to the possibility of an abnormal nature of the child's growth. This may be the cause of changes in the development both of the spine and the pelvic bones.

Tyrakowski et al. [66] examined the spinopelvic parameters in adult patients with Scheuermann's disease. Meanwhile, in contrast to Jiang et al. [65], they specify that PI changes only in the first decade of life, and remains unchanged in adolescence and adulthood. They examined a group of 40 patients with Scheuermann's disease (average age is 25) and noted a reduction in all spinopelvic parameters in comparison with normal parameters: PI – 40°, PT – 7°, SS – 33°, and SVA – 22 mm. PI indicators in male and female patients differed slightly. Moreover, there are no reliable differences in this parameter in patients with thoracic and thoracolumbar kyphosis. There was no significant correlation between PI and LL. The authors emphasize that this case contrasts with the data of other researchers [70], who noted a high degree of correlation between PI and LL in healthy people. Tyrakowski et al. [66] proposed that a slight correlation between PI and LL in patients with hyperkyphosis is a consequence of an increase in thoracic or thoracolumbar kyphosis compensated by an increase in LL. It is necessary to keep a neutral sagittal balance. The fact that the PI in patients with Scheuermann's disease (both men and women) is significantly lower than in healthy people and differs little from the indicators of healthy children suggests the following: Scheuermann's disease, which develops in growing adolescents, can affect the process of pelvic development, eventually resulting in low PI values.

Many surgeons [5, 11, 12, 39, 44, 52, 55, 57, 58, 62, 71, 72] studied the spinopelvic parameters in patients operated by them. Almost all of them noted the absence of any major changes in PI, PT and SS in the immediate and long-term postoperative periods. Only the study of Guler et al. can be mentioned [72]. These authors stated a noteworthy growth in SS and decrease in PT, while SVA and PI remained unchanged. In return, McDonnell et al. [5] marked a significant change

in the position of SVA relative to S1 (reduction of sagittal disbalance).

There have been repeated attempts to link the junctional kyphosis with the value of spinopelvic parameters. Lonner et al. [14], who operated on 78 patients, observed the development of PJK in 25 (32.1 %) patients. The authors identified a direct correlation between the value of the proximal junctional angle and the value of PI, which, in turn, correlated with the value of LL – both initial and that at the end of the follow-up period (but not TK). PI has been defined as a fixed anatomical parameter directly determining LL value. This factor defines the individual features of posture, but is not associated with TK value. Changes in spine arrangement (the result of disc pathology, spondylolisthesis, the consequences of spinal fusion) require the presence of mobile segments to regularize the overall sagittal balance. This mechanism is defined by a fixed PI at spinal column base. The authors suggest that PI is an essential indicator determining the magnitude of correction during multilevel spinal fusion surgery, when the number of free segments involved in preserving compensation is relatively small. In patients with PJK, the PI value correlates with PJK value. When correcting the TK, the balance is preserved by free segments above and below the block zone. This process is influenced by PI value. It seems that the upper thoracic spine is more susceptible to this type of complication, since it is initially kyphotic.

Nasto et al. [47] operated on 37 patients; seven of them had the PJK development. The initial TK value is the same in both groups (81.3°); this also refers to LL (70.8° vs. 71.6°). In PJK group, PI was considerably higher (51.9° vs. 42.7°), PT and SS also prevailed, but to a lesser extent (17.4° vs. 9.5° and 34.4° vs. 33.2°, respectively). Meanwhile, SVA index in patients with PJK was considerably lower (-8.2 versus -12.3 mm). Postoperative indicators of TK and LL were almost equal. Nevertheless, since the preoperative PI was higher in the PJK group, the postoperative deficit of the lordosis index was considerable in comparison with the group without PJK. Lordosis reduces after TK correction. Thus, the magnitude of kyphosis correction should be planned in conformance with the preoperative PI to avoid excessive smoothing of lordosis. The larger PI, the smaller the kyphosis correction should be to prevent excessive smoothing of LL. The authors propose a formula for defining the final volume of lumbar lordosis: correction LL (%) = 0.66 × correction TK (%) = 2.0.

If LL does not correspond to PI, there is a so-called lumbopelvic mismatch (LL-PI), and such patients have an elevated risk of PJK.

Lonner et al. [57] reported the outcomes of surgical treatment of 96 patients (23 cases of PJK development). All spinopelvic parameters remained constant. The authors give the following data for groups with and without PJK before and after surgery: PI: 44–42° vs. 44-44°; PT: 17–16° vs. 12–15°; SS: 33–29° vs. 31–26°. All the differences are equivocal. This also applies to SVA. In PI < 45°, patients with PJK had a greater postoperative kyphosis (58° vs. 42°) than those without PJK. In patients with PI ⩾ 45° in the presence of PJK, postoperative kyphosis was less (23° vs. 39°). Personalization of kyphosis correction prevents the discrepancy between the kyphosis magnitude and PI as well as reduces the PJK risk.

Zhu et al. [62] operated on 45 patients with thoracic and thoracolumbar kyphosis. PI is considerably higher in the group of thoracic deformities both before and after surgery. All parameters and SVA remained completely unchanged, despite the deformity type, the presence or absence of DJK.

McDonnell et al. [5] compared one- and two-stage interventions. Only SVA showed statistically significant differences before and after surgery (a sharp reduction in imbalance) in both groups. The other parameters changed insignificantly.

After kyphosis correction, the remaining mobile segments should compensate and restore the sagittal spine alignment. The possibility of reaching this depends on the number of free segments and on PI value. This parameter does not correlate with the frequency of junctional kyphosis. Nevertheless, in the presence of PJK, its magnitude directly correlates with PI value [14]. If thoracic kyphosis is subjected to excessive correction in the presence of significant PI, considerable tension develops in the lumbar region, as well as in the upper thoracic non-instrumented segments. This happens to achieve a congruous global and regional sagittal balance, including the spinopelvic one. An excessive tension can cause the development of distal or proximal junctional kyphosis. Minor junctional kyphosis is usually asymptomatic. However, it can progress, resulting in problems and reoperations. Insufficient correction, in turn, causes the formation of hyperlordosis, degeneration of the discs, and pain syndrome. Thus, when planning an operation, it is essential to consider the initial PI value to achieve a balanced spine shape in sagittal plane.

Therefore, the spinopelvic parameters in patients with Scheuermann's disease are considerably lower than in the general population (both in adolescents and adults). They do not tend to change after surgical correction of kyphosis. And as for their connection with the risk of developing PJK and DJK, there is no consensus today. That is why new research is required.

Prevention of junctional kyphosis. A single solution has not yet been worked out. Nevertheless, attempts are being made to formulate basic guidelines for reducing the junctional kyphosis frequency. Regarding PJK, it is essential to mention the recommendations of Sardar et al. [9]:

– optimization of bone mineral density 6 months before surgery (with regard to Scheuermann's disease, probably not very relevant);

– normalization of SVA (closer to 40 mm) and LL (closer to PI – 10.0°);

– in patients with TK greater than 40°, the UIV should be located in the upper thoracic spine; this statement directly relates to the problem of Scheuermann's disease. Nevertheless, inclusion in the zone of UEV block is not assessed uniquely by everyone;

– use of soft landing in the area of the proximal end of block zone. The problem of reducing mechanical tension at the points of transition between the spinal fusion zone and free segments is solved in different ways. According to some authors, when using pedicular fixation in the proximal junctional zone, screws should be replaced with hooks. The latter are less rigid anchor elements and create a smooth transition from fixed to non-fixed spinal segments [56]. Others recommend to keep two threads outside the cortical bone plate when implanting screws at the UIV level [51]. Chinese orthopedists [59] reported on the experience of using satellite rods in addition to standard ones to enhance the corrective effect and prevent junctional kyphosis. They used the so-called duet screws (screws allowing to fix two parallel rods) for additional fixation of the spine at the apex of deformity, as well as above and below the zone of Ponte osteotomy by 1–3 segments, depending on the degree of rigidity of the kyphotic curve. As a result, the zone of double rod fixation appeared to be several segments shorter than the fixation zone with standard rods. A smooth transition was created: standard plus satellite rods – standard rods – free segments. Comparison of two groups of patients (22 in each) demonstrated that satellite rods allow for a larger volume of correction (40.7° vs. 32.6°), a smaller loss of correction (1.0° vs. 2.4°), as well as a considerable decline in PJK (4.5 % vs. 31.8 %) and DJK (4.5 % vs. 9.1 %);

– contouring of rods to match kyphosis (light) in the proximal part of the structure;

– cement reinforcement of UIV and UIV+ 1 bodies in patients with osteoporosis (in relation to Scheuermann's disease, it is not relevant);

– preservation of the dorsal ligament complex, joint capsules and paraspinal musculature at the level of the proximal part of the spinal fusion area.

Regarding the problem of DJK prevention, there is a lack of consensus: the choice of the first lordotic vertebra as LIV (lower than FLD) or SSV. Nevertheless, surgeons favor the latter option more often.

Discussion

Junctional kyphosis is one of the complications that very often accompany surgical interventions aimed at correcting spinal deformities of various etiologies. The main cause of their development is suboptimal planning of the length of instrumented block zone, i.e. localization of the proximal and distal instrumented vertebrae. Spinal deformities in the sagittal plane are no exception in this sense. First of all, this applies to progressive severe kyphosis due to Scheuermann's disease. The number of patients undergoing surgical treatment for Scheuermann's disease is quite large and is gradually growing. Coe et al. [73] published data from SRS M&M Committee (Scoliosis Research Society Morbidity and Mortality Committee): from 2001 to 2004, 683 patients with Scheuermann's disease were operated by SRS members. Jain et al. [74] analyzed the data of the Nationwide Impatient Sample database. They reported about 2,796 patients operated on in the USA in 2000–2008. Meanwhile, the number of operated patients increased steadily – 2.9 times in total. Horn et al. [75] have analyzed the KID Impatient Database (the largest pediatric database in the USA). They found 1070 cases of Scheuermann's disease for the period from 2003 to 2012. During this period, the number of patients (per 100,000 population) grew from 3.6 to 7.5. 787 (76.3 %) patients underwent surgical treatment. Moreover, the proportion of operated patients has not changed over the years and amounted to 72.8 %.

We have tried to study the maximum possible number of papers devoted to junctional kyphosis development in patients with Scheuermann's disease. The study of world databases (Scopus, Web of Science) and its comparison with the list of references let us assume that there is a minimum number of sources of useful information outside the investigated literature array.

The incidence of PJK and DJK was, according to the analysis of this material, 11.8 and 5.9 %, respectively, PJF – only 0.3 %. Considering that junctional kyphosis develops and proceeds asymptomatically in the vast majority of cases, and is found only with a thorough analysis of postoperative spondylograms, it could be concluded that interest in these pathological conditions is somewhat overestimated. This could also be evidenced by the rarity of PDF development (0.3 %) and reoperations (45 per 2110 patients). Yet such a conclusion seems completely unreasonable. To evaluate the importance of any clinical phenomenon, it must be investigated in dynamics. Meanwhile, the number of articles devoted to the long-term (more than five years) results of surgical correction of kyphosis associated with Scheuermann's disease is extremely limited [3, 39, 61, 76]. Moreover, only one of them analyzes the dynamics of PJK frequency during the long (on average – 18 years) postoperative period: the number of cases of junctional kyphosis increases from 31 to 53 % during this time. This data forces us to refuse hasty conclusions. It requires to continue the collection of clinical cases.

Scheuermann's kyphosis is spinal deformity in the sagittal plane. The study of their dynamics is impossible without considering the spinopelvic parameters. Literature data suggest that the spinopelvic parameters in patients with Scheuermann's disease are considerably less than in the general population (both in adolescents and adults). They do not have a tendency to change after surgical correction of kyphosis, and their connection with the risk of junctional kyphosis is assessed ambiguously by researchers.

While analyzing outcomes, most surgeons are trying to identify risk factors for the development of PJK and DJK. Frequently they come to diametrically opposite conclusions. Consequently, there is a wide range of opinions regarding prevention techniques for the development of this complication and defining the optimal extent and boundaries of spinal instrumented fusion.

One of the leading spine surgeons of our time, Prof. Dubousset has performed

only 9 operations to correct Scheuermann's kyphosis. He severely restricted indications for these interventions [77].

In his opinion, PJK after spinal fusion is not a matter of hooks, screws, wires, ligaments and connectors. It is a matter of local balance of the so-called Cephalic Vertebra.

He identified three main disadvantages of practiced preoperative planning:

1) it is based on radiography and 3D reconstructions in statics;

2) segmental mobility and the amplitude of movements above and below the spinal fusion area are neglected, especially the reserve of extension in the hip joints;

3) the ratio of the masses of the head, chest, abdomen, pelvis, and lower extremities is not taken into account.

We suggest that these guidelines should be taken very carefully.

Conclusions

This review is the largest in terms of literary sources coverage on the topic under discussion. Its content strongly suggests that the problem of distal and proximal junctional kyphosis development in the surgery of Scheuermann's disease is far from being resolved. New studies are required.

The main disadvantage of our review is the following: literature analysis was conducted in undifferentiated manner. It is based on the age of patients. Nevertheless, most published articles present the treatment outcomes of mixed cohorts of patients, which renders it practically impossible to divide them by age at the time of surgical intervention.

The study had no sponsors. The authors declare that they have no conflict of interest.

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Address correspondence to:
Mikhaylovskiy Mikhail Vitalyevich
Novosibirsk Research Institute of Traumatology and Orthopaeducs n.a. Ya.L. Tsivyan,
17 Frunze str., Novosibirsk, 630091, Russia,
MMihailovsky@niito.ru

Received 13.10.2021
Review completed 17.09.2021
Passed for printing 20.09.2021

Mikhail Vitalyevich Mikhaylovskiy, DMSc, Prof., chief researcher, Department of Pediatric Vertebrology, Novosibirsk Research Institute of Traumatology and Orthopaeducs n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0002-4847-100X, MMihailovsky@niito.ru.