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Research Paper
Cervical Range of Motion Following Scheuermann Kyphosis Corrective Surgery

Mohammadreza Chehrassan[1], Farshad Nikouei[1], Mohammadreza Shakeri[1], Gholamreza Azarnia[1*], Javad Moeini[1*], Farid Abiri[1], Hasan Ghandhari[1]

1. Bone and Joint Reconstruction Research Center, Shafayahyaian Hospital, Iran University of Medical Sciences, Tehran, Iran.

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ABSTRACT

Background: Surgical correction of Scheuermann's kyphosis is an effective treatment for severe deformities; however, its impact on cervical range of motion (ROM) remains underexplored, particularly in certain populations.

Objectives: This study aimed to evaluate the changes in cervical ROM following surgical correction of Scheuermann's kyphosis and to identify factors influencing postoperative outcomes.

Methods: A total of 32 patients with Scheuermann's kyphosis who underwent posterior spinal correction and fusion from July 2021 to October 2023 were included in this prospective study. Cervical ROM (flexion, extension, lateral bending, and rotation) was measured preoperatively and at 2-month, 6-month, and 1-year follow-ups using a standardized goniometer-based method. Demographic parameters, radiological measures, instrumentation details, and kyphosis apex levels were recorded. Statistical analysis was performed to assess correlations between cervical ROM reductions and surgical factors, including the upper instrumented vertebra (UIV), lower instrumented vertebra (LIV), and preoperative curve flexibility.

Results: Cervical ROM decreased significantly across all planes of motion one year postoperatively. Flexion and extension showed the highest reductions (20.33% and 19.84%, respectively), while right and left rotation exhibited the least changes (11.59% and 13.21%, respectively). Greater preoperative kyphosis severity and lower curve flexibility were associated with more significant ROM reductions, particularly in flexion and extension ($P<0.05$). Patients with UIV at T3 or T4 experienced greater reductions in flexion, right bending, and right rotation, while those with LIV at L4 had the most significant extension reduction ($P=0.002$). The type of instrumentation (screw vs. hook) at UIV did not significantly affect ROM outcomes.

Conclusion: Surgical correction of Scheuermann's kyphosis results in a significant reduction in cervical ROM, particularly in flexion and extension. Preoperative kyphosis severity, curve flexibility, and instrumentation levels are key factors influencing these outcomes. These findings underscore the importance of individualized surgical planning and postoperative rehabilitation to mitigate cervical mobility loss and optimize patient function.

*** Corresponding Authors:**
Gholamreza Azarnia, MD.
Address: *Bone and Joint Reconstruction Research Center, Shafayahyaian Hospital, Iran University of Medical Sciences, Tehran, Iran.*
E-mail: *razarnia65@gmail.com*

Javad Moeini, MD.
Address: *Bone and Joint Reconstruction Research Center, Shafayahyaian Hospital, Iran University of Medical Sciences, Tehran, Iran.*
E-mail: *saeenmedicine@gmail.com*

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Introduction

Scheuermann's kyphosis is the most common form of thoracic hyperkyphosis, characterized by structural abnormalities of the vertebral bodies and intervertebral discs, most notably anterior wedging of the vertebrae. This condition typically develops during puberty and is more frequently observed in males [1–5]. The reported prevalence of Scheuermann's disease varies widely, depending on the criteria used for diagnosis, and ranges from 0.4% to 8% [6–9].

The management of Scheuermann's kyphosis depends on the severity of the deformity and the associated symptoms [10, 11]. For patients with severe kyphosis, surgical intervention has demonstrated significant success in reducing deformity, improving quality of life, and facilitating a return to daily activities [12–14]. While the benefits of surgery are well-documented, postoperative complications have also been reported, including a reduction in cervical spine range of motion (ROM). This reduction is thought to be influenced by multiple factors, including altered biomechanics due to compensatory mechanisms for the kyphotic deformity, changes in the alignment of adjacent spinal segments, and the effects of surgical stabilization on cervical mobility. Studies have shown that kyphotic deformities lead to increased stress on adjacent segments, contributing to restricted motion and potential stiffness in the cervical spine [15, 16].

Studies investigating cervical ROM changes following surgery for Scheuermann's kyphosis have yielded varying results, suggesting that these changes may differ across populations and surgical techniques [17–20]. Despite the significance of this issue, there is limited evidence specifically addressing Scheuermann disease. Given the prevalence of Scheuermann's kyphosis and the importance of understanding its postoperative outcomes, this prospective study was designed to evaluate the impact of corrective surgery on cervical spine ROM in patients with Scheuermann's kyphosis. This study aimed to provide insights into the potential changes in cervical ROM and contribute to the body of evidence on the outcomes of kyphosis correction surgery.

Methods

From July 2021 to October 2023, 32 patients diagnosed with Scheuermann's kyphosis were enrolled in this prospective study. Demographic data were extracted from patients' records and documented. Radiological parameters, including measurements of Scheuermann's kyphosis and cervical lordosis, were assessed preoperatively and during follow-ups at two months, six months, and one year postoperatively. Statistical correlations were primarily performed using cervical ROM data obtained one year after surgery.

All patients underwent a posterior surgical approach using a consistent surgical technique. The upper instrumented vertebra (UIV) and lower instrumented vertebra (LIV) and implant type (screw or hook) were recorded for each patient. The apex of the kyphotic curve was identified and classified into three regions: T2–T5, T5–T10, and T10–L2. Curve flexibility was evaluated preoperatively using a bolster X-ray.

Cervical ROM, including flexion, extension, lateral bending (right and left), and rotation (right and left), was measured for all patients at four time points: preoperatively, and at two months, six months, and one year postoperatively. Measurements were taken using Goniometer® software installed on an Android smartphone. The smartphone was mounted on a helmet secured to the patient's head (Figure 1). To standardize the measurements, patients were instructed to stand in their natural posture while the software was reset. Movements were performed in the following sequence:

Flexion and extension: Patients executed forward flexion and backward extension, with the X-axis serving as the reference.

Lateral bending: Patients bent laterally to the right and left, with the Z-axis as the reference.

Rotation: Patients rotated their heads to the right and left, with the Y-axis serving as the reference.

During each movement, efforts were made to minimize displacement along the other axes, ensuring accurate and consistent readings.

This study was conducted following the approval of the institutional ethics committee. All patient information was kept confidential and handled exclusively by the research team. Ethical principles outlined in the Helsinki Declaration and the ethics committee were strictly adhered to throughout the study.

Results

A total of 32 patients met the inclusion criteria and were enrolled in the study. Of these, 20(62.5%) were

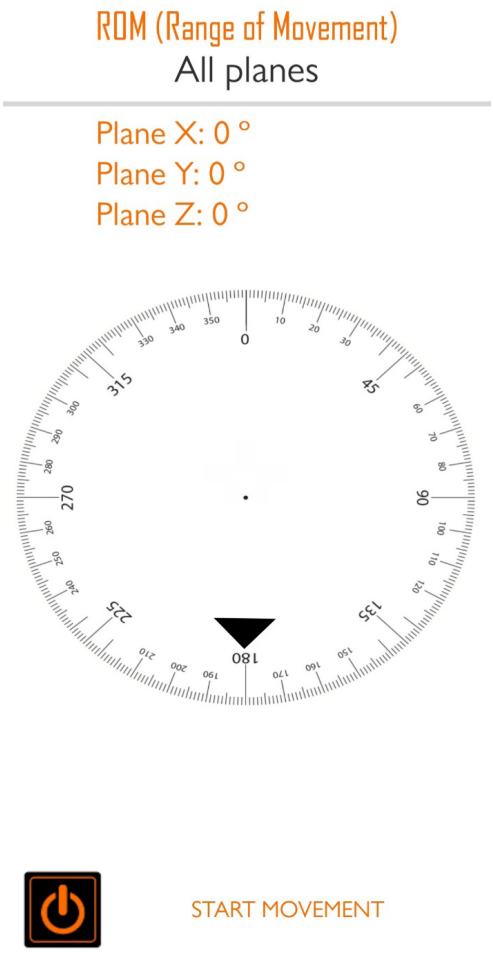

Figure 1. Screenshot of the Goniometer® software used to measure cervical ROM during flexion, extension, lateral bending, and rotation, with real-time angular tracking via X, Y, and Z axes

male, and 12(37.5%) were female. The mean age at the time of surgery was 17.31±4.3 years, ranging from 15 to 22 years. The mean preoperative kyphosis angle was 82.77±12.73°, which significantly decreased postoperatively to 41.31±11.50°. Cervical lordosis decreased from a mean of 22.06±18.44° preoperatively to 11.38±5.23° postoperatively, a statistically significant reduction (P=0.03). The apex of the kyphotic curve was located in the T5–T7 region in 2 patients (6.25%), T8–T9 in 8 patients (25%), and T10–T12 in 22 patients (68.75%). Mean pre-operative correction achieved using a hyperextension bolster X-ray was 32.6%.

Instrumentation levels varied across patients: the UIV was T2 in 24 cases (75%), and T3 or T4 in 8 cases (25%). The LIV was L1 in 2 patients, L2 in 8 patients, L3 in 16 patients, and L4 in 6 patients. Screws were the most commonly used fixation devices, utilized in 68.75% of cases at the UIV and in 100% of cases at the LIV. Hooks were used in 31.25% of cases at the UIV.

Across all cervical movements, there was a significant reduction in ROM at one year post-surgery. The greatest percentage reductions were observed in flexion (20.33%) and extension (19.84%), while the smallest reductions occurred in right rotation (11.59%) and left rotation (13.21%). Similar trends were noted at two months and six months postoperatively. At six months, the greatest reductions were in flexion (22.49%) and extension (20.29%), with the smallest reductions in right rotation (12.9%) and left rotation (14.18%) (Table 1).

An inverse correlation was observed between age and cervical ROM across all parameters; however, only the correlation between age and extension was statistically significant, with older patients showing greater reductions in extension (P<0.001). Gender did not show a statistically significant relationship with cervical ROM reductions.

An inverse correlation was observed between preoperative kyphosis and cervical ROM across most dimensions, except for left rotation. Statistically significant

Table 1. Mean values of cervical ROM measured preoperatively and at follow-up intervals (2 months, 6 months, and 1 year postoperatively)

Cervical ROM Parameter	Mean±SD			
	Pre-operative	2 Months Postoperatively	6 Months Postoperatively	1 Year Postoperatively
Flexion	74.44±14.03	59.38±13.41	57.75±13.51	56.6±13.15
Extension	69±9.78	55.31±12.05	55±12.25	55±11.36
Rt bending	54.75±10.94	46.5±11.51	45.81±12	44.31±12.09
Lt bending	52.25±8.17	47.75±8.5	46.19±8.16	44.75±8.5
Rt rotation	71.69±13.61	63.38±13.86	62.44±13.72	60.94±13.05
Lt rotation	70.5±10.07	61.19±13.03	60.5±13.21	58.88±13.77

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correlations were found between preoperative kyphosis and flexion (P<0.001), extension (P=0.01), and left bending (P=0.01). However, no significant relationship was found between the degree of postoperative kyphosis correction and cervical ROM. Curve flexibility, as assessed with the bolster X-ray, showed a positive correlation with cervical ROM. Lower percentages of curve correction were associated with greater reductions in ROM. This correlation was statistically significant for flexion, extension, and right rotation (P<0.05). An inverse correlation was observed between postoperative cervical lordosis and cervical ROM, with a statistically significant relationship identified only for extension (P=0.015).

The UIV significantly influenced reductions in flexion, right bending, and right rotation (P<0.05), with greater reductions observed in patients whose UIV was at T3 or T4. At the LIV, a significant difference was found only for extension (P=0.002), with the greatest reduction seen in patients with LIV at L4 (Table 2). The type of device used at the UIV (screw or hook) did not have a statistically significant effect on cervical ROM (Table 3).

Discussion

Despite the clinical significance of cervical ROM changes following Scheuermann kyphosis surgery, there is a notable scarcity of similar studies in the literature, particularly those focusing on diverse populations or employing standardized measurement techniques. This study evaluated cervical ROM in patients with Scheuermann kyphosis before and after surgical correction. The findings provide valuable insights into the effects of surgery on cervical spine mobility, highlighting significant reductions in ROM across all planes of motion at one year postoperatively. Flexion and extension demonstrated the greatest reductions, whereas rotational movements exhibited the least decline.

Table 2. Percentage reduction in cervical ROM in correlation with the UIV and LIV

Cervical ROM Parameter	Upper Level (%)			P	Lower Level (%)				P
	T2	T3	T4		L1	L2	L3	L4	
Flexion	29.81	52.34	50	<0.001	27.94	35.47	44.05	37.1	0.13
Extension	21.06	20.71	12.94	0.47	20.95	20.17	14.12	40.27	0.002
Rt bending	35.88	33.03	23.33	0.04	47.93	26.87	24.64	25.71	0.44
Lt bending	35.04	9.61	8	0.07	40.29	26.1	19.13	30	0.53
Rt rotation	21.07	39.6	5.71	0.02	15.64	24.57	14.8	18.31	0.57
Lt rotation	18.1	32.34	7.69	0.12	13.77	29.42	23.42	16.67	0.23

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Table 3. Percentage reduction in cervical ROM in correlation with the type of instrument in UIV

Cervical ROM Parameter	UIV (%)		P
	Hook	Screw	
Flexion	24.6	24.7	0.64
Extension	21.19	19.82	0.31
Rt bending	25.45	16.14	0.17
Lt bending	21.48	17.91	0.57
Rt rotation	11.32	16.82	0.28
Lt rotation	14.29	17.57	0.57

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The observed decrease in cervical ROM aligns with previous reports suggesting that correcting thoracic kyphosis can alter cervical spine biomechanics [17–22]. In the present cohort, flexion and extension showed the highest percentage of ROM reduction (20.33% and 19.84%, respectively); these numeric values are observations from our patients and should not be read as exact replications of others' series. Qualitatively, the predominance of sagittal-plane loss in our data is consistent with reciprocal cervical alignment changes described after thoracic hyperkyphosis correction [23] and with foundational descriptions of cervical kinematics and compensation [24].

The cervical spine commonly compensates for thoracic hyperkyphosis by increasing cervical lordosis; correcting the thoracic deformity removes or reduces that compensation and changes load distribution at the cervicothoracic junction. This biomechanical rationale underpins why sagittal-plane movements (flexion/extension) showed the largest decreases in our series. Xu et al. documented reciprocal changes in cervical lordosis after Scheuermann correction and discussed clinical consequences, such as associations with proximal junctional kyphosis and patient-reported outcomes [23].

In contrast, axial rotation in the cervical spine is largely governed by segmental kinematics of the occiput–C1, C1–C2 and subaxial levels. In vivo three-dimensional studies have shown that rotation is produced predominantly by upper- and mid-cervical segmental motions and is coupled differently from pure sagittal-plane motions; this helps explain why axial rotation in our cohort was relatively less affected by thoracic correction [25, 26].

Lateral bending displayed intermediate reductions in our patients, consistent with three-dimensional kinematic analyses that identify distinct coupling patterns and magnitudes for lateral bending across cervical levels [27]. These multidimensional coupling relationships mean that surgical changes in thoracic alignment will affect each cervical plane differently.

Preoperative deformity severity and curve rigidity were significant predictors of postoperative cervical ROM loss in our series: patients with larger baseline thoracic kyphosis and lower flexibility experienced greater reductions in flexion, extension, and lateral bending. This finding echoes clinical series reporting that the magnitude and rigidity of the primary deformity strongly influence postoperative radiographic and functional outcomes after Scheuermann correction [28, 29]. Clinicians should therefore consider preoperative kyphosis angle and flexibility when counseling patients about expected postoperative cervical mobility.

Surgical strategy exerted a measurable influence on cervical ROM. Longer constructs and constructs that extend closer to the cervicothoracic junction were associated with greater reductions in cervical motion; in our cohort, UIV at T3–T4 produced larger decreases in certain planes than UIV at T2, and LIV at L4 was associated with greater extension loss, consistent with the notion that construct length and junctional level change global mechanics and adjacent-segment behavior [30, 31]. Prior comparative series and junctional analyses support the influence of construct extent and junctional mechanics on adjacent-segment stiffness and junctional complications [30, 31].

Interestingly, implant type at the UIV (screw versus hook) did not produce a statistically significant difference in postoperative cervical ROM in our sample. This suggests that construct position and length are the dominant mechanical determinants of adjacent cervical mobility, more so than the specific implant type used at the UIV, a conclusion supported by comparative surgical series that emphasize levels and construct strategy as primary drivers of outcomes [30, 31].

Clinical implications

The measurable reductions in cervical ROM after thoracic deformity correction highlight the need for: (1) specific preoperative counseling about possible changes in cervical mobility (particularly in flexion/extension), (2) surgical planning that takes into account patient expectations and the mechanical consequences of construct length/UIV choice, and (3) early, targeted postoperative rehabilitation focused on preserving cervical sagittal mobility when appropriate. Long-term follow-up is also warranted because adjacent-segment phenomena (degeneration or junctional kyphosis) can evolve over time after fusion procedures [31, 32].

Conclusion

Surgical correction of Scheuermann kyphosis results in significant reductions in cervical ROM, particularly in flexion and extension. Preoperative kyphosis severity, curve flexibility, and instrumentation levels are important factors influencing postoperative outcomes. These findings underscore the importance of individualized surgical planning and postoperative management to mitigate the impact on cervical spine mobility and optimize patient outcomes.

Limitations

This study's limitations include a modest sample size and reliance on a single, standardized goniometer-based measurement method for cervical ROM rather than instrumented motion analysis or dynamic fluoroscopy; although our measurement technique was applied consistently (same device/operator/protocol), more granular kinematic studies could add information on segmental behavior. In addition, longer follow-up and multicenter validation would strengthen generalizability. Future studies could incorporate instrumented motion analysis or 3D kinematic assessment to capture segmental contributions to cervical motion.

Ethical Considerations

Compliance with ethical guidelines

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Authors' contributions

Conceptualization and study design: Mohammadreza Chehrassan and Gholamreza Azarnia; Data gathering: Gholamreza Azarnia and Farid Abiri; Data analysis: Mohammadreza Chehrassan and Javad Moeini; Writing the original draft preparation: Javad Moeini; Review and editing: Farshad Nikouei and Mohammadreza Shakeri; Software development: Mohammadreza Chehrassan; Accountability for all aspects of the work: Hasan Ghandhari.

Conflict of interest

The authors declared no conflict of interest.

References

[1] Kim HJ, Iyer S. Proximal junctional kyphosis. J Am Acad Orthop Surg. 2016; 24(5):318-26. [DOI:10.5435/JAAOS-D-14-00393] [PMID]

[2] Jain AK, Dhammi IK, Jain S, Mishra P. Kyphosis in spinal tuberculosis-Prevention and correction. Indian J Orthop. 2010; 44(2):127-36. [DOI:10.4103/0019-5413.61893] [PMID]

[3] Ailon T, Shaffrey CI, Lenke LG, Harrop JS, Smith JS. Progressive spinal kyphosis in the aging population. Neurosurgery. 2015; 77(suppl_4):S164-72. [DOI:10.1227/NEU.0000000000000944] [PMID]

[4] Pizzutillo PD. Nonsurgical treatment of kyphosis. Instr Course Lect. 2004; 53:485-91. [PMID]

[5] Hinman MR. Comparison of thoracic kyphosis and postural stiffness in younger and older women. Spine J. 2004; 4(4):413-7. [DOI:10.1016/j.spinee.2004.01.002] [PMID]

[6] Chehrassan M, Shakeri M, Nikouei F, Toulany M, Faraji M, Habibollahzadeh A, et al. Comparison of MRI and bolster hyperextension radiography in determining the flexibility of thoracic curves in Scheuermann kyphosis: A retrospective cross-sectional study. Curr Orthop Pract. 2023; 34(1):60-5. [DOI:10.1097/BCO.0000000000001192]

[7] Lowe TG. Scheuermann's kyphosis.Neurosurg Clin N Am. 2007; 18(2):305-15. [DOI:10.1016/j.nec.2007.02.011] [PMID]

[8] Yaman O, Dalbayrak S. Kyphosis and review of the literature. Turk Neurosurg. 2014; 24(4):455-65. [DOI:10.5137/1019-5149.JTN.8940-13.0] [PMID]

[9] Damborg F, Engell V, Andersen M, Kyvik KO, Thomsen K. Prevalence, concordance, and heritability of Scheuermann kyphosis based on a study of twins. J Bone Joint Surg Am. 2006; 88(10):2133-6. [DOI:10.2106/JBJS.E.01302] [PMID]

[10] Khan BI, Yost MT, Badkoobehi H, Ain MC. Prevalence of scoliosis and thoracolumbar kyphosis in patients with achondroplasia. Spine Deform. 2016; 4(2):145-8. [DOI:10.1016/j.jspd.2015.08.003] [PMID]

[11] Mirzashahi B, Chehrassan M, Arfa A, Farzan M. Severe rigid Scheuermann kyphosis in adult patients; correction with posterior-only approach. Musculoskelet Surg. 2018; 102(3):257-60. [DOI:10.1007/s12306-017-0526-4] [PMID]

[12] Lim M, Green DW, Billinghurst JE, Huang RC, Rawlins BA, Widmann RF, et al. Scheuermann kyphosis: Safe and effective surgical treatment using multisegmental instrumentation. Spine. 2004; 29(16):1789-94. [DOI:10.1097/01.BRS.0000134571.55158.01] [PMID]

[13] Huq S, Ehresman J, Cottrill E, Ahmed AK, Pennington Z, Westbroek EM, et al. Treatment approaches for Scheuermann kyphosis: A systematic review of historic and current management. J Neurosurg Spine. 2019; 32(2):235-47. [DOI:10.3171/2019.8.SPINE19500] [PMID]

[14] Faldini C, Traina F, Perna F, Borghi R, Martikos K, Greggi T. Does surgery for Scheuermann kyphosis influence sagittal spinopelvic parameters? Eur Spine J. 2015; 24 (Suppl 7):893-7. [DOI:10.1007/s00586-015-4253-y] [PMID]

[15] Sardar ZM, Ames RJ, Lenke L. Scheuermann's kyphosis: Diagnosis, management, and selecting fusion levels. J Am Acad Orthop Surg. 2019 May 15;27(10):e462-72. [DOI:10.5435/JAAOS-D-17-00748] [PMID]

[16] Guler O, Akgul T, Korkmaz M, Gunerbuyuk C, Sariyilmaz K, Dikici F, et al. Postoperative changes in sacropelvic junction in short-segment angular kyphosis versus Scheuermann kyphosis. Eur Spine J. 2017; 26(3):928-36. [DOI:10.1007/s00586-016-4756-1] [PMID]

[17] Quek J, Pua YH, Clark RA, Bryant AL. Effects of thoracic kyphosis and forward head posture on cervical range of motion in older adults. Man Ther. 2013; 18(1):65-71. [DOI:10.1016/j.math.2012.07.005] [PMID]

[18] Shaghayegh Fard B, Ahmadi A, Maroufi N, Sarrafzadeh J. Evaluation of forward head posture in sitting and standing positions. Eur Spine J. 2016; 25(11):3577-82. [DOI:10.1007/s00586-015-4254-x] [PMID]

[19] Li J, Zhang D, Shen Y. Impact of cervical sagittal parameters on axial neck pain in patients with cervical kyphosis. J Orthop Surg Res. 2020; 15(1):434. [DOI:10.1186/s13018-020-01909-x] [PMID]

[20] Siasios I, Winograd E, Khan A, Vakharia K, Dimopoulos VG, Pollina J. Cervical sagittal balance parameters after single-level anterior cervical discectomy and fusion: Correlations with clinical and functional outcomes. J Craniovertebr Junction Spine. 2018; 9(1):56-62. [DOI:10.4103/jcvjs.JCVJS_9_18] [PMID]

[21] Machino M, Yukawa Y, Hida T, Ito K, Nakashima H, Kanbara S, et al. Cervical alignment and range of motion after laminoplasty: Radiographical data from more than 500 cases with cervical spondylotic myelopathy and a review of the literature. Spine (Phila Pa 1976). 2012; 37(20):E1243-50. [DOI:10.1097/BRS.0b013e3182659d3e] [PMID]

[22] Singla D, Veqar Z. Association between forward head, rounded shoulders, and increased thoracic kyphosis: A review of the literature. J Chiropr Med. 2017; 16(3):220-9. [DOI:10.1016/j.jcm.2017.03.004] [PMID]

[23] Xu L, Shi B, Qiu Y, Chen Z, Chen X, Li S, et al. How does the cervical spine respond to hyperkyphosis correction in Scheuermann's disease? J Neurosurg Spine. 2019; 31(4):493-500. [DOI:10.3171/2019.3.SPINE1916] [PMID]

[24] Bogduk N, Mercer S. Biomechanics of the cervical spine. I: Normal kinematics. Clin Biomech (Bristol, Avon). 2000; 15(9):633-48. [DOI:10.1016/S0268-0033(00)00034-6] [PMID]

[25] Ishii T, Mukai Y, Hosono N, Sakaura H, Nakajima Y, Sato Y, et al. Kinematics of the upper cervical spine in rotation: in vivo three-dimensional analysis. Spine (Phila Pa 1976). 2004; 29(7):E139-44. [DOI:10.1097/01.BRS.0000116998.55056.3C] [PMID]

[26] Ishii T, Mukai Y, Hosono N, Sakaura H, Fujii R, Nakajima Y, et al. Kinematics of the subaxial cervical spine in rotation in vivo: Three-dimensional analysis. Spine (Phila Pa 1976). 2004; 29(24):2826-31. [DOI:10.1097/01.brs.0000147806.31675.6b] [PMID]

[27] Ishii T, Mukai Y, Hosono N, Sakaura H, Fujii R, Nakajima Y, et al. Kinematics of the cervical spine in lateral bending: In vivo three-dimensional analysis. Spine (Phila Pa 1976). 2006; 31(2):155-60. [DOI:10.1097/01.brs.0000195173.47334.1f] [PMID]

[28] Lonner BS, Newton P, Betz R, Scharf C, O'Brien M, Sponseller P, et al. Operative management of Scheuermann's kyphosis in 78 patients: Radiographic outcomes, complications, and technique. Spine (Phila Pa 1976). 2007; 32(24):2644-52. [DOI:10.1097/BRS.0b013e31815a5238] [PMID]

[29] Koller H, Juliane Z, Umstaetter M, Meier O, Schmidt R, Hitzl W. Surgical treatment of Scheuermann's kyphosis using a combined antero-posterior strategy and pedicle screw constructs: Efficacy, radiographic and clinical outcomes in 111 cases. Eur Spine J. 2014; 23(1):180-91. [DOI:10.1007/s00586-013-2894-2] [PMID]

[30] Lee SS, Lenke LG, Kuklo TR, Valente L, Bridwell KH, Sides B, Blanke K. Comparison of Scheuermann kyphosis correction by posterior-only pedicle screw fixation versus combined anterior/posterior fusion. Spine (Phila Pa 1976). 2006; 31(20):2316-21. [DOI:10.1097/01.brs.0000238977.36165.b8] [PMID]

[31] Glattes RC, Bridwell KH, Lenke LG, Kim YJ, Rinella A, Edwards C 2nd. Proximal junctional kyphosis in adult spinal deformity following long instrumented posterior spinal fusion: Incidence, outcomes, and risk factor analysis. Spine (Phila Pa 1976). 2005; 30(14):1643-9. [DOI:10.1097/01.brs.0000169451.76359.49] [PMID]

[32] Hashimoto K, Aizawa T, Kanno H, Itoi E. Adjacent segment degeneration after fusion spinal surgery: A systematic review and meta-analysis. Int Orthop. 2019; 43(4):987-93. [DOI:10.1007/s00264-018-4241-z] [PMID]

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