■ INSTRUCTIONAL REVIEW: SPINE

Scheuermann's kyphosis; current controversies

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This review of the literature presents the current understanding of Scheuermann's kyphosis and investigates the controversies concerning conservative and surgical treatment. There is considerable debate regarding the pathogenesis, natural history and treatment of this condition. A benign prognosis with settling of symptoms and stabilisation of the deformity at skeletal maturity is expected in most patients. Observation and programmes of exercise are appropriate for mild, flexible, non-progressive deformities. Bracing is indicated for a moderate deformity which spans several levels and retains flexibility in motivated patients who have significant remaining spinal growth.

The loss of some correction after the completion of bracing with recurrent anterior vertebral wedging has been reported in approximately one-third of patients. Surgical correction with instrumented spinal fusion is indicated for a severe kyphosis which carries a risk of progression beyond the end of growth causing cosmetic deformity, back pain and neurological complications. There is no consensus on the effectiveness of different techniques and types of instrumentation. Techniques include posterior-only and combined anteroposterior spinal fusion with or without posterior osteotomies across the apex of the deformity. Current instrumented techniques include hybrid and all-pedicle screw constructs.

Scheuermann's deformity is the most common cause of angular progressive structural thoracic or thoracolumbar hyperkyphosis with associated back pain in adolescence. It has an incidence of 4% to 8% and no gender predominance.[1] The condition has a familial occurrence often affecting monozygotic twins with a strong genetic contribution to the aetiology.[2] Elevated levels of growth hormone may be present and contribute to the pathological process. Thickening of the anterior longitudinal ligament which occurs across the levels of the kyphosis, as well as reversal of anterior vertebral wedging during bracing, support the major role of mechanical factors in the pathogenesis.

Clinical presentation and imaging studies

Patients usually present between late childhood and adolescence with increasing thoracic or thoracolumbar kyphosis creating a sharp gibbus. A compensatory lumbar hyperlordosis often produces a negative sagittal balance and increased cervical lordosis causing goose-neck deformity with anterior protrusion of the head. The development of a fixed, angular kyphosis has cosmetic implications for the patients with dissatisfaction in relation to their appearance. A dull, non-radiating pain around the apex of the deformity with local tenderness is commonly the presenting symptom, associated with tightness of the hamstrings and iliopsoas and stiffness of the anterior shoulder girdle. One-third of patients have mild scoliosis, spondylolysis of L5 or lumbosacral spondylolisthesis.[1]

The radiological diagnosis can be established in the presence of a kyphosis > 45° with anterior wedging of three or more consecutive vertebrae by 5°, the presence of irregular vertebral end-plates with Schmorl's nodes and narrowing of the intervening intervertebral disc spaces.[1,3]

Thoracic kyphosis should be measured from the most proximal to the most distal vertebra included in the curve using the Cobb method.[4,5] Lateral spinal radiographs should be taken in the standing position with forward elevation of the shoulders and arms by 90° or with both arms resting on the ipsilateral clavicles (clavicular position).[6] The pelvis and hips should be included to allow calculation of spinopelvic parameters. The extent and apex of the deformity, as well as the first lordotic disc, should be defined. The structural stiffness of the kyphosis can be assessed on supine lateral radiographs with the patient lying in

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hyperextension over a bolster. Spinal MRI should be performed, particularly if surgical correction is planned, to exclude intraspinal anomalies, prolapse of a thoracic disc and compression of the cord at the apex of the kyphosis.

Differential diagnosis

This includes postural round-back kyphosis consisting of a mild increase in thoracic kyphosis to 60°, which is smooth, non-progressive and correctable in hyperextension or in the supine position. The apical vertebrae and adjacent discs have a normal appearance without wedging, irregularities of the end-plate or premature degeneration of the disc.

Natural history

There is limited information on the long-term prognosis of patients with Scheuermann's kyphosis who are not treated. There are also no data available on the long-term outcome after surgical correction. The condition is expected to have a benign course with no severe disability after completion of spinal growth. Patients with severe curves can develop progressive deformities with deteriorating back pain into adult life, as well as the potential for neurological complications secondary to degenerative spondylosis and disc herniation.[7]

Murray, Weinstein and Spratt[8] compared the quality of life and functional level of 67 adults with a mean Scheuermann's kyphosis of 72° at a mean follow-up of 32 years with those of 32 age- and gender-matched control subjects. They found no difference between the groups in the type of job, the incidence of back pain, the need for pain medication, sick leave due to back pain, the presence of numbness in the lower limbs, restriction of recreational activities, the frequency of exercise and perceived activity level. Thoracolumbar deformity caused more functional limitations compared with thoracic curves. Both groups had similar rates of marriage, but patients with a kyphosis > 85° were more often single. The level of education did not differ between the patients and the control group, and no difference was found in regard to self-consciousness or self-esteem. As age advanced, concern over appearance often receded. No difference was observed in the association of the apex and the degree of kyphosis with the prevalence of tenderness along the spine, hamstring tightness, strength of the trunk muscles, and range of movement. Patients with curves > 85° also had lower inspiratory capacity. The study concluded that patients with untreated Scheuermann's kyphosis may have some functional limitations, but no major interference with their lives.[8]

Neurological complications

Neurological deficits can be caused by compression of the spinal cord because of progressive deformity, disc herniation or an extradural cyst developing at the apex of the kyphosis.[9] Putz et al[10] reported the presence of dysplastic posterior elements producing cord compromise in immature patients. Ryan and Taylor[11] reported three patients aged between 14 and 20 years who developed acute compression of the cord at the apex of a moderate kyphosis with a mean angle of 54° without any disc protrusion. They believed that factors influencing neural compression included the degree of kyphosis, the number of vertebrae involved, the rate of progression, local anatomical variations, trauma and secondary impairment of the vascular supply to the cord.[11] Kapetanos et al[9] described a 14-year-old patient with a Scheuermann's kyphosis of 66° who presented with a neurological deficit due to herniation of a thoracic disc. The authors reviewed the literature and found reports of 20 patients with moderate kyphosis (mean 56.3°) who developed compromise of the cord because of disc protrusion.[9] Of these, seven were skeletally immature and 13 were adults, including seven who were a minimum of 35 years of age. This suggests that there is a gradually increasing risk of degeneration of thoracic discs which causes pressure on the cord as age progresses. Disc degeneration occurred mainly at the apex of the kyphosis. An increased risk of neural complications was correlated with sharply angulated, short-segmented curves.[9]

Treatment

This depends primarily on the severity of pain and the development of neurological and cosmetic symptoms, but also on the degree and progression of the deformity in relation to the remaining spinal growth.

Physiotherapy. This includes hamstrings stretching, strengthening of trunk extensors and core stability exercises. It does not affect the progression of the kyphosis and is recommended for symptomatic patients with short flexible curves or as an adjunct to bracing in order to prevent stiffening of the spine. Weiss, Dieckmann and Gerner[12] followed 351 patients aged between 17 and 21 years who had been treated by physiotherapy, osteopathy and manual therapy and in whom pain measurement scales had been recorded. Each scale demonstrated a reduction in pain by between 16% and 32% which suggested that there was a positive benefit of treatment on levels of pain.[12]

Brace treatment. Predictors of a favourable outcome include increased flexibility of kyphosis, early instigation of bracing with kyphosis of < 65°, initial correction of the curve by > 15° in a brace, and skeletal immaturity with a minimum of one year of remaining growth.[13-15] Predictors of a poor outcome include a rigid kyphosis > 65°, vertebral wedging > 10°, and limited or no remaining spinal growth. Only one report implied that good results could be obtained when bracing was applied for a kyphosis > 75°.[16] The presence of scoliosis does not affect the outcome.[17] The brace should be worn for between 16 and 23 hours each day for 18 months, followed by wearing it for a part of each day for an additional 18 months with gradual withdrawal.[16,18]

With appropriate patient selection, bracing can achieve an improvement in the kyphosis and reversal of vertebral wedging. However, once the brace is removed the correction is partly lost in at least 30% of compliant patients, which overall makes bracing unrewarding.[13,16-19]

Table I. Summary of papers reporting on posterior shortening procedures

Authors	Number of patients	Type of surgical procedure*	Type of posterior releases/ shortening procedures	Type of instrumentation
Herrera-Soto et al[34]	19	A/PSF	Apical Ponte osteotomies in all patients	Hybrid construct
Hosman et al[35]	33	PSF 16; A/PSF 17	Segmental facetectomies in all patients	Hybrid construct
Lee et al[36]	39	PSF 18; A/PSF 21	Apical Smith-Petersen osteotomies in 12 of 18 PSF patients, none in A/PSF patients	PSF, all-pedicle screw construct; A/PSF, hybrid hook/screw construct
Johnston et al[39]	27	PSF 20; A/PSF 7	Closing-wedge laminar resections in all patients	Hybrid construct
Geck et al[40]	17	PSF	Apical Ponte osteotomies in all patients	All-pedicle screw construct
Koptan et al[38]	33	PSF 16; A/PSF 17	Osteotomies in 12 of 16 PSF patients (mean 5 levels), none in A/PSF patients	PSF, all-pedicle screw construct; A/PSF, hybrid construct

* A/PSF, anterior and posterior spinal fusion; PSF, posterior spinal fusion

Surgical indications. There is controversy about the indications for surgical treatment because of limited evidence on the natural history of the condition with regard to pain, the level of function or disability, self-esteem and deterioration of the kyphosis for treated and untreated patients, as well as the risks associated with corrective surgery.[20] Surgical correction in adolescents can be recommended for progressive severe deformities of > 70° which cannot be controlled by bracing, in the presence of disabling pain resistant to non-operative measures including modification of activity, exercises and the administration of anti-inflammatory agents for a minimum of six months, or in patients who express genuine concern regarding their appearance.[21-30]

The decision to proceed with corrective surgery should be made after the possible risks and anticipated benefits have been carefully balanced and discussed with the patients and their families. The severity of the symptoms and the patient's self-perception are more important in decision-making for surgery than the degree of kyphosis. The surgeon should evaluate his ability to produce a predictable correction with few complications.

Biomechanical principles of kyphosis correction. Scheuermann's kyphosis affects the thoracic or thoracolumbar spine at a level of the cord which is susceptible to neurological injury. The vertebral column is shortened anteriorly and the cord has adjusted to reduced length due to the developing kyphosis. As the deformity progresses, the cord is gradually attenuated and compressed at the apex of the kyphosis, especially in the presence of bulging of the disc. Surgical correction of sharply angular curves will produce lengthening of the anterior column, which carries an increased risk of neurological compromise because of acute lengthening of the cord. It is therefore necessary to perform simultaneous shortening of the posterior vertebral column by multisegmental osteotomies across the apical levels of the deformity to avoid stretching the cord during correction.[1,27,31] Despite this obvious principle there is limited information on the use of posterior shortening procedures during the correction of a kyphosis (Table I).

Surgical techniques. These have evolved from posterior spinal fusion without implants[3] to instrumented correction followed by fusion.[21,23,25,29] Correction of the kyphosis with instrumentation can be performed using posterior-only or combined anteroposterior procedures. The instrumentation has developed from the use of Harrington and Luque[7,21,23,25,29,32] rods to hybrid or all-pedicle screw constructs.[30,33-38] Current controversies include the need for additional anterior release compared with posterior-only correction, as well as the use of hybrid as opposed to pedicle-screw instrumentation.[35-39] There is also lack of consensus on the recommended type of posterior shortening procedure that should be used during correction of the kyphosis.[34-36,38-40]

It has been reported that patients treated by pre-operative traction and uninstrumented spinal fusion followed by cast immobilisation had high rates of nonunion and significant post-operative loss of correction.[3] Harrington rods have been used in addition to pre-operative traction and post-operative casting for six to nine months. The rate of complications remained high, including loss of correction, pseudarthrosis, rod breakage and failure of the hook-bone interface because of the increased forces acting on the convexity of the deformity, wound infection, junctional kyphosis, neurological deficits, deep-vein thrombosis, duodenal compression and schizophrenia.[21,23,25,29] The addition of an anterior release was not associated with improvement in the outcome or complication rate.[7]

Luque instrumentation was introduced to provide segmental fixation and to reduce the risk of nonunion and recurrence of the deformity.[41] However, the neurological risks associated with the passage of sublaminar wires, the need for a post-operative plaster jacket or brace, the high rate of further surgery to remove protruding or broken rods and the development of a junctional kyphosis proximal to the instrumentation discouraged its use.[32] Rates of nonunion remained high because of limited space available for grafting with segmental wires and rods in place. Proximal junctional

Table II. Summary of papers reporting surgical outcome, complications and rate of re-operations

Authors	Number of patients	Mean age at surgery (yrs)*	Type of surgical procedure	Type of instrumentation	Mean kyphosis (°)		Loss of kyphosis correction (°) at mean follow-up (yrs)	Complications†	Re-operations
					Pre-operative	Post-operative			
Lim et al[33]	23	19	A/PSF 20 PSF 3	Hybrid construct Proximal, hooks forming a claw (23 patients), Distal, hooks forming a claw (10), pedicle screws (13)	83	46	5.0 (3.1)	A/PSF: 3 PJK > 10°, 7 pleural effusions, 2 pneumothoraces, 1 persistent serous drainage from iliac crest site, 1 temporary bilateral upper-limb weakness/numbness PSF: none	3 patients due to loss of instrumentation fixation (sublaminar hook dislodgement/pedicle screw pull-out)
Herrera-Soto et al[34]	19	17.4	A/PSF with video-assisted thoracoscopic release	Hybrid construct Proximal & distal, hooks forming a claw, apical hook compression	84.8	45.3	1.6 (2.7)	2 pleural effusions, 2 pneumothoraces, 1 pulmonary embolism, 1 transient upper-limb numbness/weakness, 2 inferior hook pull-out	1 patient underwent revision surgery for inferior hook pullout
Hosman et al[35]	33	25.8	A/PSF 17 PSF 16	Hybrid construct Proximal, 6 pedicle hooks Distal, 4 pedicle screws	78.7	51.7	1.4 (4.5)	A/PSF: 2 wound infections 1 PJK/DJK PSF: 1 wound infection	3 patients had wound debridement due to infections, 1 patient had revision of distal fixation, 5 patients had removal of instrumentation
Lee et al[36]	39	A/PSF 18.0 PSF 17.3	A/PSF 21 PSF 18	A/PSF: hybrid construct PSF: segmental all-pedicle screw construct	A/PSF 89.1 PSF 84.4	A/PSF 51.9 PSF 38.2	A/PSF 6.1 PSF 2.2 (≥ 2.0)	A/PSF: 1 permanent paraplegia, 2 wound infections, 2 PJK, 1 inferior laminar hook pull-out, 1 DJK, 3 superficial wound infections PSF: none	3 patients required revision due to proximal (2) and distal (1) junctional kyphosis, 3 wound closures (infection)
Lonner et al[37]	78	16.7	A/PSF 42 PSF 36	A/PSF: hybrid (32 patients), all-hook (8), all-pedicle screw construct (2) PSF: all-pedicle screw (21), hybrid (10), all-hook construct (5)	A/PSF 82.6 PSF 74.4	A/PSF 55.8 PSF 46.2	A/PSF 3.2 PSF 6.4 (2.9)	A/PSF: 1 neurogenic bladder, 1 acute renal failure, 2 pleural effusions, 1 pneumothorax, 1 pulmonary embolism Both groups: 25 PJK ≥ 10°, 4 DJK ≥ 10°	3 patients required revision due to junctional kyphosis, 1 patient required repair of nonunion, 1 underwent debridement due to wound infection
Johnston et al[39]	27	PSF 16.3 A/PSF 15.6	PSF 20 A/PSF 7	Hybrid construct	PSF 80.5 A/PSF 79	PSF 38.8 A/PSF 41.6	PSF 1.1 A/PSF 1.7 (2.5)	1 asymptomatic rod fracture/no loss of correction implying no pseudarthrosis	
Geck et al[40]	17	16.4	PSF	All-pedicle screw construct, supplemented by proximal hooks (2 patients)	75.0	38.0	No patient lost > 4° (≥ 2)	PJF: 1 PJK, 1 DJK, 1 wound infection, 1 persistent nausea (mild SMA‡ syndrome) 1 sternal pain	1 patient with late wound infection and a solid fusion underwent removal of instrumentation
Koptan et al[38]	33	A/PSF 16.7 PSF 15.8	A/PSF 17 PSF 16	A/PSF: hybrid construct PSF: all-pedicle screw construct	A/PSF 79.8 PSF 85.5	A/PSF 38.8 PSF 45.1	A/PSF 3.1 PSF 2.4 (4.5)	A/PSF: 1 PJK, 1 deep wound infection, 2 superficial wound infections, 1 transverse process fracture PSF: 1 persistent thigh pain	1 patient with PJK required extension of fusion, 1 patient had unilateral screw exchange to hooks, 1 deep wound debridement

* A/PSF, anterior and posterior spinal fusion; PSF, posterior spinal fusion

† PJK, proximal junctional kyphosis; DJK, distal junctional kyphosis

‡ SMA, superior mesenteric artery

kyphosis developed due to damage to the interspinous space at the level above the proximal end of the construct.

The use of posterior fusion using hybrid instrumentation (pedicle/laminar hooks and pedicle screws) combined with an anterior release has been reported in 32 patients in whom a mean kyphosis of 85° was corrected to a mean of 43° with a mean loss of 4° at follow-up; seven patients developed a junctional deformity.[30] Lim et al[33] performed an anterior release in 20 of 23 patients, with a mean kyphosis of 83° corrected to a mean of 46° with a mean loss of 5° at follow-up. Three developed a junctional deformity and eight had a pleural effusion or a pneumothorax. Herrera-Soto et al[34] reported 19 patients who underwent anteroposterior correction using video-assisted thoracoscopic release. A mean pre-operative kyphosis of 84.8° was corrected to a mean of 45.3° with a mean loss of 1.6° at follow-up and no incidence of junctional kyphosis. Five patients developed a pleural effusion or a pneumothorax or required prolonged mechanical ventilation.

Anteroposterior correction of kyphosis has been compared with posterior-only procedures, but the selection criteria for each group have not been well defined.[35-37] Hosman et al[35] compared 16 patients who underwent posterior-only with 17 who had an anteroposterior fusion with a mean follow-up of 4.5 years. The two groups were matched for age, gender, pre-operative kyphosis, curve flexibility and follow-up. Posterior correction included facetectomies and the use of hybrid constructs. The mean pre- and post-operative and follow-up values were comparable between the groups, with no significant loss of correction of the deformity.

Lee et al[36] compared 18 patients who had posterior correction using segmental pedicle-screw constructs with 21 who had undergone anteroposterior instrumented fusion using hybrid instrumentation at a minimum follow-up of two years. No patient in the anteroposterior group and 12 of the 18 in the posterior group had Smith-Petersen osteotomies. This is a posterior osteotomy for correction of a fixed sagittal deformity, comprising removal of the posterior elements, undercutting the adjacent spinous processes and closing the osteotomy, thereby creating an opening of the spine through the disc space. The groups were matched for age, pre-operative kyphosis and levels of posterior fusion. Surgical time and blood loss were significantly less in the posterior group. The mean pre-operative kyphosis was 84° in the posterior and 89° in the combined group. This was corrected to a mean of 38° in the posterior group with a mean loss of 2°, compared with a mean of 52° in the combined group with a mean loss of 6°. No complications occurred in the posterior group. In the anteroposterior group three patients developed a junctional deformity, one had permanent paraplegia and three a wound infection. In this study, posterior segmental pedicle-screw instrumentation with Smith-Petersen osteotomies achieved greater correction of the deformity and fewer complications compared with anteroposterior procedures with hybrid constructs.[36]

Lonner et al[37] retrospectively analysed 42 and 36 patients with Scheuermann's kyphosis from ten institutions who had anteroposterior or posterior surgery, respectively, using hybrid or all-screw constructs. In the anteroposterior group the mean kyphosis of 82.6° was corrected to 55.8° with a mean loss of 3.2° at follow-up. In the posterior group the mean kyphosis of 74.4° was corrected to 46.2° with a greater mean loss of 6.4°. Complications in the anteroposterior group included a neurogenic bladder, acute renal failure, pleural effusion, pneumothorax and pulmonary embolism in one patient each, compared with none in the posterior group. A mean proximal junctional kyphosis of 21.5° occurred in 25 patients and a mean distal junctional kyphosis of 22° in four, across the whole series. Three patients with junctional problems required extension of the fusion.

Johnston et al[39] compared 20 patients who had posterior with seven who had anteroposterior correction using hybrid constructs. Closing-wedge laminar resections were performed in all. A mean kyphosis of 80.5° was corrected to 37.9° at follow-up in the posterior group, while a mean kyphosis of 79.0° was corrected to 42.6° in the anteroposterior group with little loss of correction post-operatively. The authors concluded that anteroposterior surgery provided no additional benefit in radiological outcome compared with posterior-only procedures.

Geck et al[40] reported excellent correction of the deformity in 17 patients performing posterior vertebral shortening via sequential segmental osteotomies (Ponte osteotomies) without anterior release followed by pedicle-screw fixation. A mean kyphosis of 75° was corrected to 38° with no patient losing > 4° at follow-up. One patient each developed a proximal and distal junctional kyphosis and late infection. There were no neurological complications.

Koptan et al[38] compared 16 patients who had posterior correction using pedicle-screw constructs with a mean of five-level posterior osteotomies with 17 matched patients in whom staged anteroposterior procedures with hybrid constructs had been performed. A mean kyphosis of 85.5° was corrected to a mean of 40.4° with a mean loss of 2° in the posterior group compared with a mean kyphosis of 79.8° which was corrected to a mean of 41° with a mean loss of 2.4° in the anteroposterior group. Blood loss, surgical time and hospital stay were significantly less in the posterior group. The authors concluded that the use of a multilevel pedicle screw technique allowed rigid fixation for posterior correction of the deformity without the need for anterior release.

Surgical complications. The data on the surgical outcome, complications, and the rate of re-operation in previous papers are summarised in Table II.

Neurological complications can develop because of acute lengthening of the cord, especially if posterior shortening is not used. Intra-operative monitoring of the spinal cord, recording motor and somatosensory evoked potentials, should be routinely used.[27] Loss of the trace mainly occurs during posterior osteotomies or the correction of the kyphosis through cantilever manoeuvres.

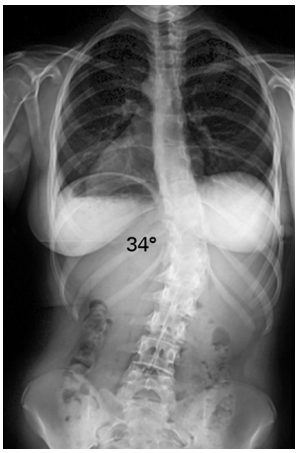

Fig. 1a

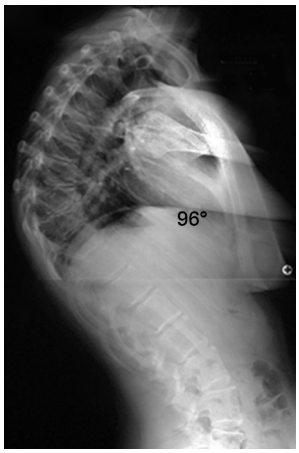

Fig. 1b

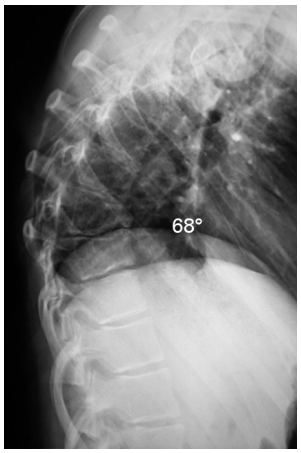

Fig. 1c

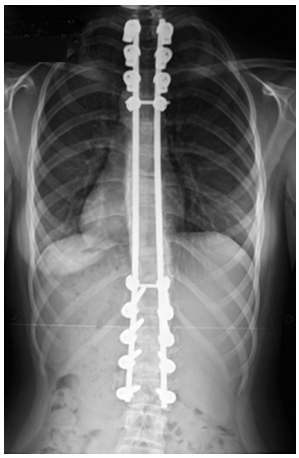

Fig. 1d

Fig. 1e

Radiographs of a patient aged 15 years and seven months, showing a) an anteroposterior view of a right thoracolumbar scoliosis measuring 34°, b) a lateral view of a thoracic Scheuermann's kyphosis measuring 96°, c) a supine bolster lateral view in hyperextension, and d) and e) posteroanterior and lateral views, respectively, at latest follow-up 2.5 years after posterior spinal fusion from T2 to L3 with closing-wedge osteotomies from T5 to T12 (seven levels). There is a kyphosis of 45°, good global sagittal balance of the spine, and no scoliosis.

Failure of the implant and pseudarthrosis with recurrent deformity can occur because of continuous bending moments acting upon the thoracic spine and the mechanical disadvantage of the bone graft being required to heal under tension. Wound infection may require removal of instrumentation resulting in progression of the deformity even if fusion has been obtained.

Junctional kyphosis developing at either end of the construct often requires extension of the fusion. A kyphotic correction > 50% results in negative sagittal balance with subsequent development of a proximal junctional kyphosis as a compensatory mechanism.[37] Anteroposterior procedures increase the risk of proximal or distal junctional kyphosis even when using modern instrumentation.[37] In patients with a proximal junctional kyphosis its magnitude correlated directly with the degree of pelvic incidence; pelvic incidence correlated directly with the lumbar lordosis but not kyphosis.[37]

Pelvic incidence is a fixed angle which describes the relationship of the sacrum to the acetabulum or pelvis. The angle is subtended by a line from the centre of the femoral head to the midpoint of the sacral endplate. A second line is perpendicular to the midpoint of the sacral end-plate. A low pelvic incidence implies a low pelvic tilt and lumbar lordosis; a high pelvic incidence reflects pelvic retroversion with increased lumbar lordosis.

Lim et al[33] observed a proximal junctional kyphosis in all patients in whom the fusion stopped at T4 and in none when it extended to T2. Distal junctional kyphosis was not found if the fusion included the first lordotic disc. It was concluded that the fusion should extend from T2 to incorporate the first lordotic segment and aim to reduce the

kyphosis to around the upper end of the normal range (40° to 50°), so that a negative sagittal balance is not produced post-operatively. There is currently limited information on the correlation between the degree of pre-operative kyphosis, compensatory lumbar lordosis, and the correction achieved with surgery and the spinopelvic parameters, such as pelvic incidence, pelvic tilt and sacral slope. This information may allow better prediction as to the optimum correction of the deformity for individual patients based on their specific sagittal spinopelvic parameters in order to produce a balanced spine and prevent the possible development of a junctional kyphosis.

Complications relating to the surgical approach occur primarily during anteroposterior open or thoracoscopic corrective procedures with an incidence of 25% to 40% and with more than 15% to 20% being of a major nature. Most are pulmonary including pleural effusion, pneumothorax and haemothorax.[7,33,34] Anterior spinal approaches also carry a risk of life-threatening complications, as well as long-term morbidity. The increased risk of complications was acceptable at times when anteroposterior surgery was considered to produce more predictable results combined with Harrington rods.[7,21] In contemporary practice with corrective techniques focusing on posterior shortening osteotomies in conjunction with rigid and versatile instrumentation and comparable correction of deformity through posterior-only procedures every effort should be made to avoid major pulmonary and other medical complications. Excellent rates of correction and almost no complications relating to the approach have been reported following posterior surgery with segmental osteotomies using hybrid or screw constructs.[36-40] The better understanding of the biomechanical forces to which implants are subjected has resulted in the development of stiffer hybrid and pedicle-screw constructs and reduced implant cut-out, rod failure, nonunion and loss of correction.

In terms of selection between hook/screw or all-screw constructs, complications associated with hybrid instrumentation have been extensively reported[30,33,34,36-38] while the more recent pedicle-screw constructs are still at an initial stage of introductory enthusiasm. More widespread usage may be associated with a high complication rate. Segmental pedicle fixation decreases the risk of screw pull-out, but may limit the ability to perform extensive posterior closing-wedge osteotomies and restrict the area available for bone grafting. Proximal fixation of hybrid constructs using claw configuration with supralaminar and pedicle hooks can destroy the interspinous space cephalad to the construct and increase the risk of proximal junctional kyphosis. Pedicle hook fixation across three or four levels at the proximal end preserves the interspinous space and facet joints between the instrumented vertebrae and the level above, reducing the risk of proximal junctional kyphosis (Fig. 1). This combined with distal fixation using pedicle screws at three to four segments allows extensive posterior osteotomies across the most rigid levels of the deformity, as well as placement of abundant bone graft to achieve a solid fusion.

Conclusions

Scheuermann's kyphosis is a benign, self-limiting condition with few symptoms persisting beyond maturity in most patients. However, severe kyphosis above 70° can continue to progress into adult life and cause significant cosmetic deformity, major dissatisfaction, mechanical back pain and the potential for respiratory or neurological complications. Bracing has a limited role for small curves in growing patients, but the kyphosis and anterior wedging can recur after the end of treatment. Surgical correction can be associated with significant complications which should be discussed with the patients when this is being considered. Contemporary instrumentation and posterior spinal shortening techniques allow correction of the kyphosis to be performed mostly through a posterior-only approach. Shortening of the posterior vertebral column is required through multilevel osteotomies to reduce the risk of lengthening of the spinal cord which can lead to major neurological complications. Hybrid instrumentation has longer documented results and has provided effective correction of the kyphosis. All-pedicle screw constructs have been associated with excellent initial reports, but with an increased neurological risk because of multiple pedicle-screw placement, and a higher cost of the implant.

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