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Scheuermann Kyphosis

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Scheuermann disease was initially described as a rigid kyphosis associated with wedged vertebral bodies occurring in late childhood.[37] The condition has been of significant orthopedic interest since that time, both because the condition is sometimes painful during its relative acute phase, and more importantly, because it causes significant truncal deformity that may be progressive. Sorensen subsequently described specific criteria for diagnosis in 1964, namely, that three adjacent vertebrae must be wedged at least 5° each.[40] Despite this, the specific criteria for the diagnosis of Scheuermann disease remain unclear in the subsequent literature. A spectrum of roundback has been described, going from postural roundback, to pre-Scheuermann disease, to classical Scheuermann disease.[45] Making these distinctions can be difficult, and the criteria on which diagnostic decisions are based are controversial.

Most articles reference Sorensen's criteria,[1,5,10,13,23,28] but others have used different criteria. These include increased thoracic kyphosis, disc space narrowing, and irregular endplates associated with a single-wedged vertebra,[3,7] kyphosis of greater than 45° with two or more wedged vertebra,[16] or "characteristic" radiographic findings (kyphosis, wedging of vertebral bodies, endplate irregularities, Schmorl's nodes).[42,43] Bradford, in various studies over time, has changed his criteria for diagnosing Scheuermann kyphosis from thoracic kyphosis of greater than 35° and at least one wedged vertebra greater than 5°,[7] to the classic Sorenson criteria,[5] to most recently, a thoracic kyphosis of greater than 45° and at least one wedged vertebra.[36] Some consider any vertebral wedging to indicate Scheuermann disease,[7,43] while others have recommended making this distinction based on curve flexibility on a lateral hyperextension radiograph of the spine.[25] Measurement of vertebral wedging can be difficult,[45] particularly in skeletally immature patients when a significant portion of the vertebral body may be unossified,[30] and the reliability of intra- and interobserver measurements has not been established. Also, no study of normal adolescents has been done to assess the flexibility/rigidity of normal thoracic kyphosis, and although Scheuermann kyphosis is described as a rigid deformity, a considerable degree of flexibility may be noted on the hyperextension lateral film.[7] Thus, even the "pathognomonic" signs of Scheuermann disease remain somewhat controversial.

This confusion points to the difficulty in defining pathologic deviations from normal with sagittal spinal alignment. Unlike scoliosis, where any significant lateral deviation in the coronal plane is abnormal, the sagittal alignment of the spine has a normal range of thoracic kyphosis. The Scoliosis Research Society has defined this range as being from 20° to 40° in the growing adolescent.[25,44,45] In a study of 316 healthy subjects with ages ranging from 2 to 27 years, the upper limit of normal kyphosis was noted to be 45°. In addition, it was noted that the average thoracic kyphosis increases with age, from 20° in childhood, to 25° in adolescents, to 40° in adults.[12] The lack of a consistent definition of Scheuermann kyphosis in the literature makes it difficult to compare studies as the inclusion criteria may be different; thus, making the distinction between the spectrum of upper normal thoracic kyphosis, severe adolescent roundback deformity, and Scheuermann disease may be impossible. Adding to the complexity are articles grouping Scheuermann disease together with spinal osteochondrosis,[41] and studies grouping patients diagnosed with abnormal juvenile kyphosis together with Scheuermann kyphosis patients when reporting the results of treatment.[16,43]

In defining Scheuermann kyphosis, the subgroup described as lumbar Scheuermann's, type II Scheuermann's, or "apprentice kyphosis" must be recognized.[2,14,45] This condition, most commonly seen in athletically active adolescent males or those involved in heavy lifting, presents with localized back pain and radiographic vertebral changes at the thoracolumbar junction, and is not typically associated with significant clinical kyphosis. The Schmorl's nodes and endplate irregularity may be so severe that lumbar Scheuermann's disease can be confused with infection, tumor, or other conditions. The etiology of lumbar Scheuermann kyphosis is unknown, but strong associations with repetitive activities involving axial loading of the immature spine favor a mechanical cause. Although the radiographic appearance may be similar, lumbar Scheuermann kyphosis may be a different entity than thoracic Scheuermann kyphosis. Unlike classic thoracic Scheuermann kyphosis, the treatment of lumbar Scheuermann disease is not controversial, as its course is nonprogressive and its symptoms resolve with rest, activity modification and time.[2,14]

Etiology

The etiology of the rigid roundback seen in classic type I Scheuermann kyphosis remains unknown. As a result, it is often categorized using nonspecific and poorly defined

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terms such as osteochondrosis or epiphysitis. Early theories included avascular necrosis of the ring apophysis,[37] inhibited enchondral ossification related to intravertebral disc herniations and endplate perforations,[38] and persistent anterior vascular grooves.[11] Subsequent studies have not verified these theories. Juvenile osteoporosis is also considered as a possible cause of Scheuermann's roundback. Conceptually, vertebrae with less than normal trabecular density would be more prone to having disc invagination via a Schmorl's node and also to have some collapse with compression. Bradford proposed this pathogenesis in a study of 12 patients after measurement of bone mineral density using the Singh index,[5] but later studies utilizing more sophisticated measurement techniques have produced conflicting findings.[13,23]

Few studies are available to describe the histologic findings in Scheuermann kyphosis,[1,19,20] and in those that are available the criteria for making the diagnosis of Scheuermann disease are not given.[20] These studies implicate defective cartilage in the vertebral growth plate and the endplate, with resultant decreased vertical growth of the anterior vertebral body as a potential cause. Abnormal collagen-proteoglycan ratios have been described in the vertebral body endplate as well.[25] As in all histologic and biochemic analyses of abnormal bone and cartilage, it is not possible to determine if the reported changes are primary or secondary to abnormal loading. An autosomal dominant inheritance pattern with high penetrance and variable expressivity has been described for Scheuermann disease, sugggesting that in some patients a biologic predisposition may be present.[17]

Most investigators agree that mechanical factors have a significant role in the pathogenesis of Scheuermann kyphosis.[1,11,14,19,20,25,37,40] Ogden believes that the term Scheuermann disease is a misnomer, stating the changes noted radiographically are altered remodeling responses to abnormal biomechanic stresses, and not secondary to an underlying disease process. He theorizes that the kyphosis occurs first, and that the anterior vertebral body is then subjected to increased forces that suppress anterior growth and perpetuate the deformity.[30] The reported success of brace treatment lends support to a mechanical etiology.[44] Patients with Scheuermann disease may have very tight hamstrings,[25] and one biomechanical theory presumes that tight hamstrings prevent anterior pelvic tilt on forward bending, focusing bending stresses on the thoracic spine.[21]

■ Incidence and Clinical Findings

The incidence of Scheuermann disease has been estimated at 1% to 8% of the population.[39,40] The typical presentation is in the late juvenile age period from 8 to 12 years, with the more severe fixed form commonly appearing between age 12 and 16 years. Patients with thoracic roundback, who have classic type I Scheuermann disease, may have pain in the thoracic spine area, but more frequently present because of patient and parental concerns related to trunk deformity. The gender prevalence of Scheuermann kyphosis is difficult to determine from the literature, and may be related to how Scheuermann kyphosis is defined. In general, males and females are involved with equal frequency,[44] although the reported ratios have varied widely.[7,28]

Patients with Scheuermann kyphosis have an angular thoracic kyphosis, often with accompanying compensatory lumbar lordosis and increased cervical lordosis. The position of the head is often in forward protrusion (so called gooseneck), and the shoulders are often positioned anteriorly as well. Forward bending typically accentuates the kyphotic deformity, with a sharply angulated bend noted in the thoracic or thoracolumbar region. The deformity is relatively fixed, remaining during attempted hyperextension of the spine. Tightness of the hamstrings is common, but the neurologic exam is usually otherwise normal. Initial radiographs include a standing posteroanterior (PA) and lateral view of the spine. The degree of kyphosis on the lateral film is measured using a modified Cobb method. In addition to increased measurable roundback on the lateral view, vertebral wedging is used to clarify the diagnosis. Associated findings of scoliosis and spondylolysis can occur with Scheuermann kyphosis, but usually are minor and do not alter treatment decisions.[10,31]

■ Natural History

The natural history of Scheuermann's disease remains very controversial. The condition tends to be symptomatic during the teenage years but often in late teenage life produces less pain.[40] In a long term follow-up study, Sorenson noted pain in the thoracic region in 50% of patients during adolescence, with the number of symptomatic patients decreasing to 25% after skeletal maturity. The pain was described as mild and not incapacitating.[40] Later authors offered a contrasting view of the symptoms of untreated Scheuermann disease, with Bradford stating that adults with Scheuermann kyphosis have a higher incidence of disabling back pain than the normal population.[4,8] Other authors of surgical series' have agreed with this, and have described pain unresponsive to nonoperative treatment as an indication for surgical treatment of Scheuermann kyphosis.[18,24,32,41]

Murray, Weinstein, and Spratt have performed a recent study designed to describe the natural history of Scheuermann kyphosis.[28] They studied 67 of a group of 118 (57%) patients diagnosed by the Sorenson criteria, using physical examination, trunk strength measurements, radiography, a detailed questionnaire, and pulmonary function testing. The patients had an average kyphotic deformity of 71°, and the average follow-up was 32 years; an age-matched comparison group was used as controls. They concluded that patients with Scheuermann kyphosis may have functional limitations, but these did not result in severe limitations due to pain,

or cause major interference with their lives. Yet in a subsequent paper, Lowe and Kasten state that adults with more severe deformities (>75°) secondary to untreated Scheuermann disease can have severe thoracic pain secondary to degenerative spondylosis and can be significantly limited by their disease.[26] Lowe and Kasten allude to the greater magnitude of the deformity as a possible explanation for the life-altering pain experienced by their patients as contrasted to those reported on by Murray et al, although studies to document a direct correlation between the amount of pain and the degree of deformity are not available.

How should the critical reader reconcile these differences of opinion regarding the natural history of Scheuermann kyphosis? Knowledge of the natural history of a disease (if no treatment is undertaken) allows the physician to determine whether or not treatment is indicated, by weighing the benefits of treatment (altering the natural history favorably) against the potential complications of treatment. Tribus has outlined the reasons for treatment of Scheuermann kyphosis into five categories: pain, progressive deformity, neurologic compromise, cardiopulmonary compromise, and cosmesis.[44] Neurologic deficits related to Scheuermann kyphosis have been very rarely reported in the literature,[6,35,46] but would be a noncontroversial indication for surgery. Neurologic deficts may be related to thoracic disc herniation, epidural cysts, or the hyperkyphosis itself, and tend to occur in adult patients. Likewise, cardiopulmonary compromise is also rare and appears to be only significant in patients with very large deformities (kyphosis > 100°).[28]

Thus, the common and somewhat controversial indications for treatment in Scheuermann kyphosis are related to pain, progression of deformity, and appearance. Pain is difficult to measure because of its subjective and temporal nature. Most of the literature on Scheuermann kyphosis states that pain is either present or absent, and does not provide data on how this was determined or measured. The study by Murray et al is the only one to attempt to objectively assess pain. They found no statistically significant difference between the Scheuermann patients and the control group with regard to the extent that pain interfered with their lives, although it is possible that a clinically significant difference might exist as 38% of the Scheuermann patients had severe interference of pain with activities of daily living compared to 21% of control subjects. The kyphotic group did have significantly higher pain intensity readings, and complained more frequently of pain in the thoracic region than the control group. Patients with Scheuermann kyphosis, however, were no more likely to take medications for back pain. They were able to study only 57% of the patients with Scheuermann kyphosis, and their statistics might be quite different if more patients were available for follow-up study.

The majority of patients with Scheuermann kyphosis presenting for treatment in adolescence do not have pain (only 26/168 in the Bradford Milwaukee brace study had pain),[7,16] yet adults with Scheuermann kyphosis are reported to seek treatment most commonly for pain.[44] Review of the available series of surgical treatment of Scheuermann kyphosis reveals that a substantial number of patients had pain listed as one of the indications for surgery (Bradford 10/228, Taylor 14/2743, Bradford 23/244, Speck 30/6541, Herndon 11/1318, Otsuka 10/10 32, Lowe 24/2424, Lowe 32/3226). Pain may be one component of Scheuermann kyphosis leading the patient to seek medical treatment, particularly in adults, but Murray et al have shown that it is not an inevitable consequence of kyphotic deformity, and it may not be severely limiting, even in patients with significant deformity. There does appear, however, to be a subset of patients with refractory pain that warrant aggressive treatment.[44]

Deformity and cosmesis are interrelated concepts. Deformity is the most common complaint of patients with Scheuermann disease, and is typically the primary reason younger patients seek medical attention. (155 of 168 patients in one series[7]) Unfortunately, the likelihood of progression of a kyphotic curve of any given degree of severity is currently not known.[32] The natural history study of Murray et al did not address the risk of progressive deformity, although this is often the prominent concern of adolescent patients who present for evaluation. Many females greatly fear having a dowager's type of humpback in middle age, and males similarly are often concerned about truncal abnormality. Unlike scoliosis, where data are available regarding assessing the risk of curve progression,[22] such studies are not yet available for Scheuermann kyphosis. Curve progression in some cases has been documented, as Bradford et al noted an increase in kyphotic deformity in 96 of 168 cases in one series and 16 of 22 cases in another.[7,8] Progression was not defined or quantified in either of these reports. The issue of curve progression is clouded also by the normal increase in thoracic kyphosis noted with aging.[12] Progression is not inevitable, however, as noted by noncompliant patients followed in the brace treatment series of Gutowski and Renshaw. They noted 11 patients were noncompliant with brace treatment, but only one of these patients had an increase in kyphotic deformity at follow-up, even though kyphosis of 54° to 90° was present in these patients.[16] Even if the risk of curve progression is not known, some patients may be extremely dissatisfied with their current trunk deformity, and as Bradford et al noted, the deformity alone may be unacceptable to the patient.[4]

The issue of deformity is significant in patients with Scheuermann kyphosis, and is usually the driving force which brings the patient to a surgeon for evaluation.[44] In a society where many juveniles and adolescents are treated vigorously for acne, have expensive orthodontic treatment for realignment of tooth and jaw abnormalities, and are increasingly concerned with body image and fashion, the importance of external appearance should

not be considered lightly. Many teenagers and their parents may be unwilling to live through life with a severe fixed roundback deformity, which gives them poor posture and may contribute to a poor self-image. Murray et al[28] attempted to address this issue in their natural history study, reporting no significant differences between the patients with Scheuermann kyphosis and the control group with regard to self-consciousness, self-esteem, or perception of being deformed. They did note a correlation between increased concern for appearance as the magnitude of the curve increased, and a positive correlation between increasing age and decreasing concern for appearance in subgroups of patients.

It should be noted that the patients in their study were older at the time of the study than those typically presenting for evaluation of Scheuermann kyphosis, with 62 of their 67 patients being older than 35 years. This is relevant to those seeing patients with Scheuermann kyphosis during adolescence and early adulthood, as this may be a time of increased body awareness and concern for cosmetics, and these patients may have different priorities during this time frame as compared to later periods in their lives. An additional finding of interest in the study of Murray et al was that patients with Scheuermann kyphosis were more frequently single than control subjects. This may have been a consequence of bias in the control group toward marriage, or that a higher percentage of men were in the study group, but a strong trend was noted suggesting patients with higher magnitude curves were more likely to be single. The relationships between posture, self-image, self-confidence, and socialization skills are undoubtedly critical to both the patient and parents who present for evaluation and treatment of roundback or Scheuermann kyphosis, but are as yet poorly understood. As surgical correction becomes more predictable and widely available, patient outcome studies will need to address self-image and self-confidence. Current experience suggests that surgical correction of a severe kyphotic deformity can radically and positively effect trunk deformity and self-esteem.

■ Treatment

Initial management of the patient presenting with Scheuermann kyphosis includes documentation and assessment of the degree of deformity and/or pain, as well as an overall "gestalt" of the negative impact of the deformity on the patient's life.[45] Physical therapy for postural improvement exercises is often recommended, focusing on hamstring and trunk extensor strengthening. A good physical therapist can also assess whether there is any tendency toward increased hip flexion contracture and may work on associated lumbar lordosis. There are no conclusive studies documenting improvement in kyphosis with exercises, although Bradford et al did note some improvement in patients with moderate degrees of deformity.[7] Teenagers often are best treated by going to a gymnasium where they can work out on machinery specifically designed to improve trunk extension, shoulder external rotation, and neck extension.

■ Brace Treatment for Kyphosis

The few available studies on efficacy of brace treatment are retrospective, have different inclusion criteria, and do not have control groups. In addition, as noted above, we do not yet have data available to allow us to predict which kyphotic curves are at significant risk for progression. Despite these shortcomings, bracing is widely regarded as being efficacious in the treatment of Scheuermann kyphosis in the skeletally immature patient.[20,25,44] Bracing has been used primarily for the treatment of deformity, with results of treatment focusing on improvement in kyphosis; the results of brace treatment for relieving pain have not been published.

The initial report of Bradford et al on Milwaukee brace treatment of Scheuermann kyphosis in 75 patients, who had completed treatment, documented a 40% decrease in mean thoracic kyphosis and a 35% decrease in mean lumbar lordosis after an average 34 months of brace wear.[7] A later study from the same center reporting on 120 of 274 patients treated with a Milwaukee brace for Scheuermann kyphosis showed a pattern of initial correction of approximately 50% of the kyphosis followed by loss of correction. The average time of brace wear was 14 months fulltime and 18 months part-time. At average 5-year follow-up, consistent brace wearers had an improvement in the kyphosis in 76 patients, worsening in 24 and no change in 10. Of the 10 patients who were noncompliant with brace wear, 2 had improvement and 8 had worsening of their kyphosis. When grouped by severity of kyphosis, compliant patients with curves having an initial magnitude of 45° to 54° had an average 5° improvement in kyphosis at final follow-up, curves of 55° to 64° degrees improved an average 7°, curves of 65° to 74° improved an average of 13°, and curves of more than 74° improved an average of 19°. The reporting of the data as averages hides some individual failures, as well as some well-documented, remarkable individual improvements in their study. They noted that 31% of compliant patients failed treatment, and defined improvement of kyphosis arbitrarily as a 3° or greater decrease in the kyphotic angle. As no study of interobserver or intraobserver reliability has been done on measurement of kyphosis, it is possible that the number of failures may be higher. Using the modified Cobb method, it is more difficult to select the endplate of the cranial end vertebra for measurement of kyphosis than for scoliosis,[45] where inter- and intraobserver errors in measurement in the 5°- to 10°-range can be expected.[15] Other authors have also documented a loss of correction of kyphosis with time out of the brace, decreasing from an initial 21° correction to 6° at final follow-up.[27]

Gutowski and Renshaw have reported on the use of the Boston lumbar and modified Milwaukee orthoses for Scheuermann kyphosis and abnormal juvenile round-

back with an average 26-month follow-up.[16] Of 75 patients in their study group, 31% completely rejected the orthosis within 4 months. Compliant patients had an average improvement in kyphosis of 27% in the Boston group and 35% in the Milwaukee group, despite use of the Milwaukee brace for older patients who had greater curves. Whether or not the corrections will be maintained with time is unknown. They recommended the Boston brace for flexible curves below 70° in magnitude with an apex at or below T7. These braces work under the assumption that flattening the excessive compensatory lumbar lordosis will result in the patient hyperextending the thoracic spine to stand erect.[16]

The "classic" prerequisites for brace treatment of Scheuermann kyphosis gleaned from these studies include that the patient have at least a 45°-curve and that those patients with a kyphosis of up to 65° may be successfully managed by bracing. Curves of greater than 74° have been associated with a higher failure rate[36], and thus this magnitude of deformity has been declared by some as an indication for surgery.[25] Candidates for bracing need to have some flexibility in the curve and must be skeletally immature (at least one remaining year of growth). The classic treatment has been a modified Milwaukee brace that has posterior pads (attached to the uprights) pushing anteriorly on the kyphosis, with both the neck and pelvis controlled by the upper and lower segment of the brace. The brace is adjusted monthly, and ideally is worn 23 hours a day for 1 to 2 years.

A critical review of the data from the bracing studies can lead to challenges of each of the above "classic" criteria. Patients with less than 64° deformity had an average improvement of kyphosis of less than 7° after prolonged brace wear in the study by Sachs et al[36]—was the time spent in the brace worth the improvement? Sachs et al concluded that an initial kyphosis of greater than 74° was associated with a higher percentage of poor results, yet their data show that 9 of 14 patients in this group had some improvement of their kyphosis. Gutowski and Renshaw reported "surprisingly effective" results with the use of a modified Milwaukee orthosis in their patients with kyphosis of 75° or greater.[16] In their initial bracing study, Bradford et al found that the amount of flexibility of the kyphosis on an initial hyperextension radiograph did not correlate with the final correction.[7] The definitive data to support use of the Milwaukee brace in preference to the Boston type, to support 1 year of brace wear over 8 or 10 months, or to support full-time wear over part-time wear are not yet available.

Complications have not been reported in the bracing series of patients with Scheuermann kyphosis, although the potential adverse psychological consequences of full-time bracing during adolescence should be considered. Current indications for bracing in Scheuermann kyphosis are evolving, but include patients with kyphosis of greater than 50° and significant pain, cosmetically unacceptable deformity, or documented progression of deformity. A commitment by the patient to wear the brace faithfully for a minimum of 1 year is required. Even with compliant brace wear by the patient, the data available at this point do not allow the prescribing physician to forecast whether brace treatment will result in improvement of deformity, prevention of progression, or failure in any particular patient. Also, a progressively greater number of teenagers refuse to wear a corrective brace.

■ Surgical Treatment

The literature on the surgical management of Scheuermann kyphosis also consists of retrospective case series', with different inclusion criteria for surgery and without control groups. Since Bradford et al first reported on posterior spinal fusion for the treatment of patients with Scheuermann kyphosis,[8] the indications for surgery and the recommended surgical technique have changed substantially. Early operative series listed deformity and/or pain as indications for surgery,[8,18,43] but more recent series have stated that surgery should be reserved for those with painful kyphosis refractory to nonsurgical management.[24,32] Still some series list deformity alone as an indication for surgery in selected patients.[26,41,43]

The indications for surgical correction remain unclear, since the natural history studies in Scheuermann kyphosis remain controversial regarding pain, disability, trunk deformity, and self-esteem. Thus, a decision for surgical correction is an individual one between the surgeon and the patient, and may depend on the patient's symptoms, self-perception, and sense of self-esteem, as well as the surgeon's training and skill in being able to predictably produce an excellent correction. Surgical indications have evolved in the past two decades, but currently include patients with greater than 75° kyphosis, or significant kyphosis (> 65°) associated with pain not alleviated by nonoperative treatment methods. Some authors also list unacceptable trunk appearance as an indication.[25] Obviously, there is some flexibility in this indication related to the surgeon and patient's interpretation of natural history data.

The results of surgical treatment of Scheuermann kyphosis can be considered relative to the two most common indications listed for surgery—relief of pain and correction of deformity. Although pain is listed as the indication for surgery in many studies, result sections of the published series tend to focus on correction of deformity. The methods of assessment of pain, either preoperatively or postoperatively, are not described in most of the series of surgical treatment. Relief of back pain related to the deformity after surgery has been reported in all of the patients in many series.[4,8,32,43] Herndon et al reported good relief of pain in 12 of 13 patients treated with combined anterior and posterior fusion.[18] Lowe reported that 18 of 24 of patients treated with staged anterior release and fusion/posterior fusion with L-rod instrumentation had greater than a 75% reduction in pain.[24] In the series of Speck and Chopin, the number of

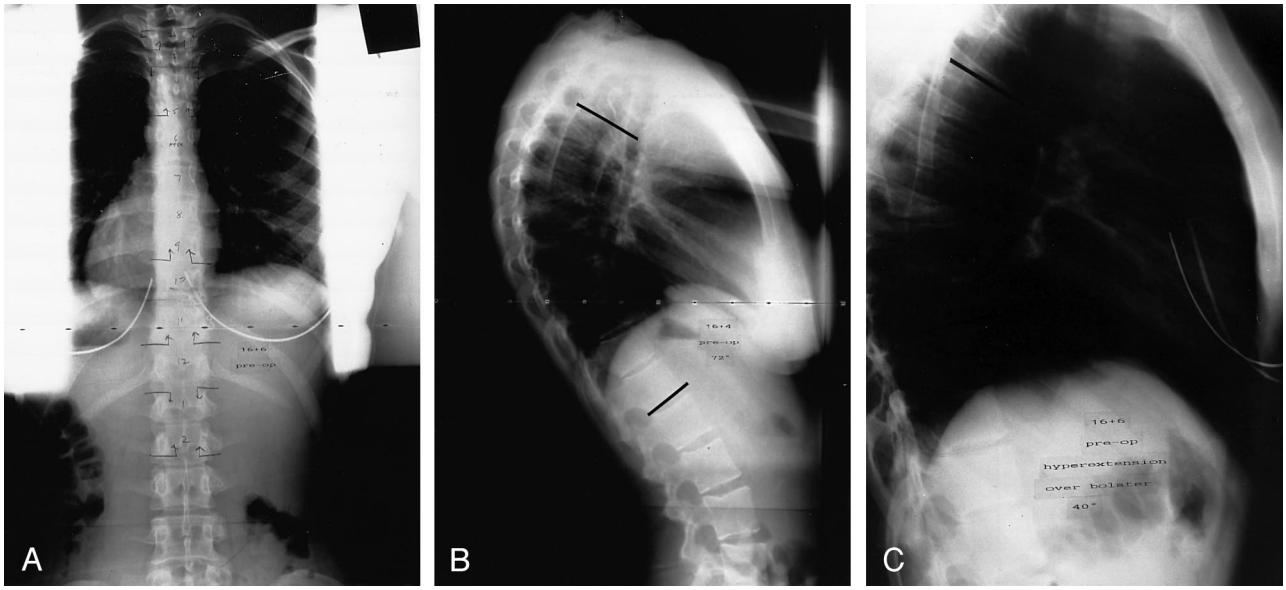

Figure 1. **A**, Standing PA spinal radiograph – in a 16-year-old girl with Scheuermann's kyphosis and severe back pain. She is skeletally mature. **B**, Standing lateral preoperative radiograph. The vertebral wedging is typical of Scheuermann's kyphosis. The kyphosis was measured as 72° (modified Cobb method). **C**, Hyperextension lateral radiograph of the thoracic spine performed over a bolster. The kyphosis reduced to 40°. PA = postero-anterior.

patients complaining of back pain decreased from 38 preoperatively to 10 following spinal fusion.[41] In a retrospective study, Lowe and Kasten evaluated a patient questionnaire, completed anonymously by 28 of 32 patients treated with anterior release and fusion/posterior Cotrel–Dubousset fusion, to assess pre- and postoperative pain and satisfaction. They reported "generally favorable" patient satisfaction regarding relief of pain, as 27 of 28 patients reported preoperative thoracic back pain that interfered with activities of daily living, while postoperatively 18 of 28 complained of mild back discomfort with vigorous activity.[26] Of interest is the comment by Bradford et al that pain relief does not appear to correlate with the degree of deformity correction.[8] Speck and Chopin did note that 5 of the 6 patients in their series with residual kyphosis greater than 60° had persistent back pain.[41] The relationship between the degree of deformity and back pain is not fully understood.

Correction of deformity by posterior spinal fusion alone using Harrington compression instrumentation was originally reported by Bradford et al, who noted excellent initial correction of deformity, but loss of correction with time. This was especially true for patients with larger kyphotic curves.[8] Taylor et al reported correction of deformity from a mean kyphotic angle of 72° to 46° at short-term follow-up.[43] Speck and Chopin have reported excellent correction of deformity in skeletally immature patients with posterior fusion alone.[41] In these series, patients were often treated with preoperative traction and postoperative cast immobilization. Otsuka et al used heavier Harrington compression rods in 10 patients and reported correction of kyphosis from a mean of 71° to 39° at 26-month follow-up. They performed posterior-only surgery if the kyphosis decreased to 50° or less on a hyperextension lateral radiograph.[32] A technique for shortening of the posterior elements and compression instrumentation has been described and presented by Ponte et al, but the results of this approach have not been published in a peer-reviewed publication.[33]

The loss of correction after posterior-only surgery has been attributed to the fusion being performed on the tension side of the spine, to inadequate strength and failure of the implants, lack of anterior support, and to inadequate initial corrections with rigid, severe deformities.[4,25] As a result, the surgical approach has been modified over time to include anterior spinal release, disc excision, and fusion in conjunction with instrumented posterior spine fusion, in an effort to improve correction and prevent late deterioration of correction (Figures 1, 2, 3).[4,18] This approach has been advocated for patients with greater than 75° of deformity, marked wedging of the apical vertebrae, and failure of the kyphosis to correct to less than 50° on a hyperextension lateral radiograph.[25,44] Initial series of anterior and posterior fusion were staged, with an intervening period of traction. As operative techniques and perioperative care have improved, same day/sequential anterior and posterior surgery has become possible and is advocated by some as having less morbidity than staged procedures.[26] Anterior and posterior surgery has generally resulted in excellent correction of deformity reported in each of the published series, with mean kyphosis decreasing from 77° to 47°,[4] 78° to 40°,[18] 82° to 50°,[41] 84° to 32°,[24] and 85° to 45°.[26]

The complications reported in the literature on operative treatment of Scheuermann kyphosis were reviewed by Murray et al,[28] who emphasize that these risks should be carefully considered relative to the natural history. The reported complications include death, postoperative

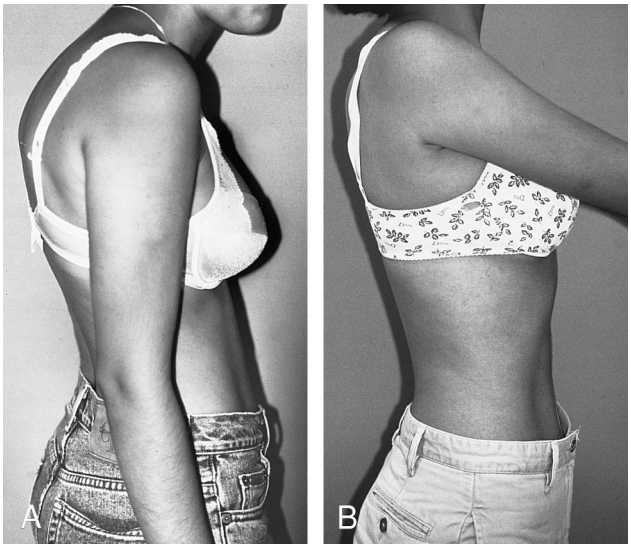

Figure 2. **A**, Standing lateral photograph of the same girl. She complained of severe thoracic back pain and had trunk deformity that was unacceptable to both the girl and her parents. **B**, Standing lateral photograph of the same patient taken 1 year after thoracoscopic anterior release, disc excision, and fusion as well as same day posterior CD horizon spinal instrumentation and fusion.

neurologic deficits, infections, gastrointestinal obstruction, intraoperative and postoperative hardware failure, pseudarthroses, prominent hardware, loss of correction, progression of kyphosis, hemothorax, pneumothorax, pulmonary emboli, and persistent back pain.[4,8,18,24,26,32,41,43] The complications encountered by Bradford et al following posterior-only surgery led them to recommend surgery only for "patients who have severe, incapacitating back pain unrelieved by conservative treatment."[8] In a later article reporting on combined anterior and posterior spine fusion, however, they state that "occasionally cosmetic reasons alone may be an indication for operation," but should not be routine "considering the magnitude of the undertaking."[4] Most authors now recommend surgical treatment only in those patients with both unremitting pain and significant kyphosis.

Despite the early recognition that "fusing too short" resulted in persistent or recurrent deformity at follow-up,[8,43] this complication persists in even the most recent series.[26] Selection of fusion levels remains a critical part of operative correction of kyphosis, yet no well-established criteria are available that have been validated with long-term follow-up. It is also not clear whether the failures in series with posterior-only surgery were secondary to the reported deficiencies of this method (fusion on the tension side, lack of anterior structural support, inadequate initial release/correction), or if the failures were related to improper selection/execution of fusion levels.

The problem of junctional kyphosis at either the proximal or distal end of the fusion mass has received more attention in the recent literature. Initial reports attributed this complication to Luque methods of spinal fixation, with disruption of the posterior ligamentous structures for passage of the most cephalad and caudal wires increasing the risk of kyphosis.[9] The complication has subsequently been reported with Coutrel–Dubousset instrumentation and is likely related to sagittal balance and selection of fusion levels.[26,45] Lowe and Kasten found that patients with Scheuermann kyphosis tend to be in negative sagittal balance, and this may become further negative with surgery, thus predisposing them to junctional kyphosis. The most recent recommendations regarding fusion levels are to include the end vertebra of the kyphosis proximally, and to extend the fusion to the first lordotic disc beyond the transitional zone distally.[26,32] To adequately correct a typical Scheuermann kyphosis, posterior corrective instrumented fusion from the T–3 to the L–2 level is necessary. Recommendations have also been made to limit correction to 50% or less of the original deformity, in an attempt to prevent later proximal junctional kyphosis.[26] Overcorrection should be avoided. The use of contemporary multisegmental rod, hook, and screw systems has increased the ability to obtain and maintain correction (as compared to Harrington compression or Luque systems). This makes the use of surgical literature published in the 1970's and 1980's regarding complications difficult to apply in current clinical situations.

Further developments in operative techniques and instrumentation for Scheuermann kyphosis include thoracoscopic anterior approaches to decrease the morbidity associated with anterior release and fusion,[29,34] as well as pedicle screw fixation at the distal aspect of the fusion construct to decrease the incidence of hardware related complications.[26] Long-term follow-up of these techniques is needed to assess their efficacy. Ideally, the spine could be corrected without fusion; however, this is currently not possible. There are no good long-term follow-up studies of surgical correction using modern surgical techniques. Further long-term research studies will be required to analyze the effect of living one's entire life with a 65° or 70° kyphosis as compared to having it reduced to 35° with surgical correction, taking into account the associated potential morbidity of junctional problems between the fused and unfused segments.

■ Conclusions

Review of the available literature on Scheuermann kyphosis reveals many shortcomings from a scientific standpoint. The etiology and even the criteria for diagnosis remain unclear. Many of the accepted principles of treatment of this disorder can be challenged, including the "high degree of success" attributed to brace treatment in skeletally immature patients. Because we cannot currently predict which kyphotic curves progress, we are unable to determine the effectiveness of brace treatment since the success of brace treatment is measured by prevention of curve progression. In the only long-term fol-

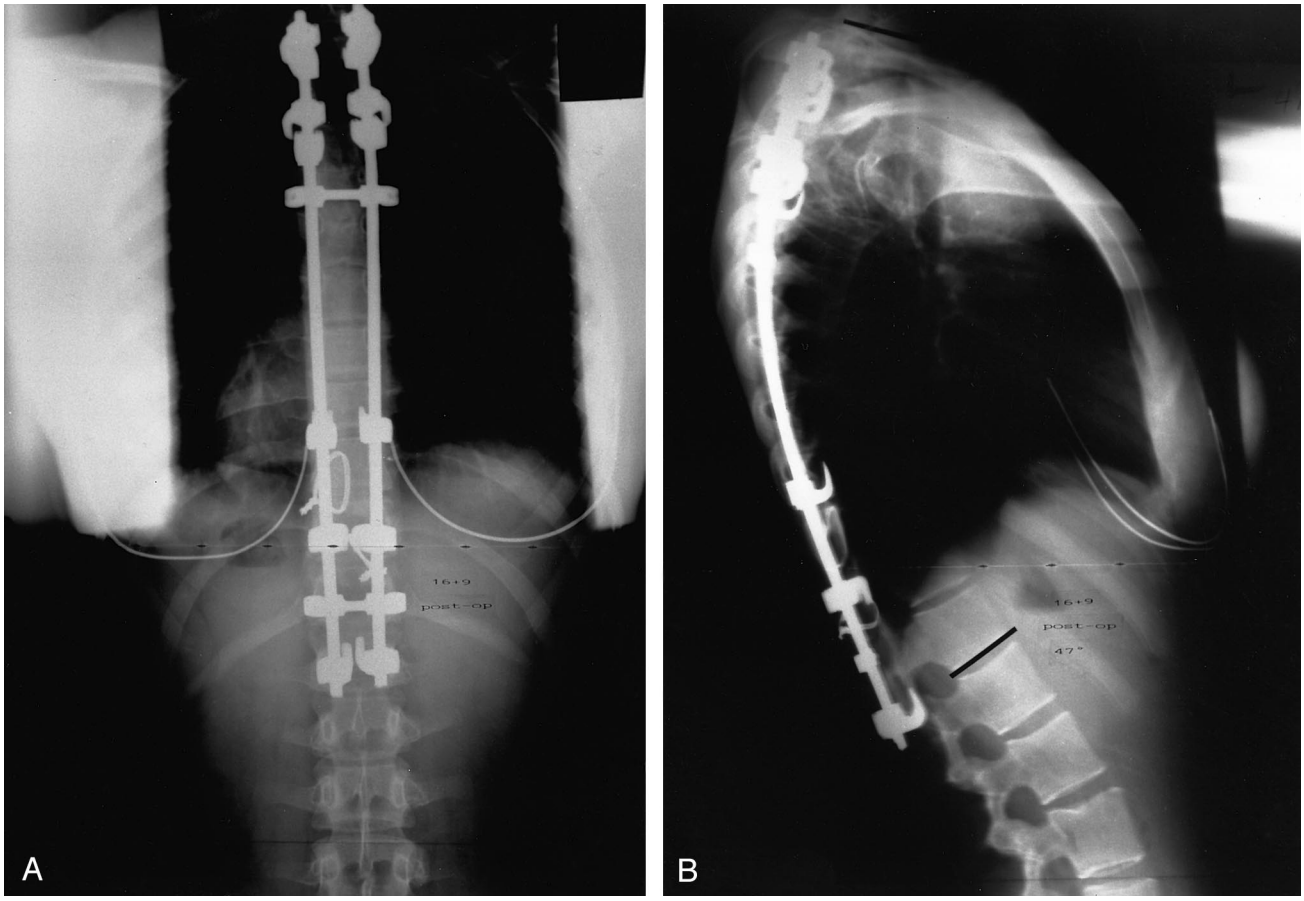

Figure 3. **A**, Postoperative PA radiograph of the spine following corrective instrumentation and fusion. **B**, Postoperative lateral radiograph following anterior disc excision and fusion via thoracoscopic approach and posterior CD horizon spinal instrumentation and fusion. The curve has been reduced to 47°. PA = postero-anterior.

low-up study of bracing for Scheuermann kyphosis, the definition of improvement was a 3° decrease in kyphosis,[36] which may be within measurement error. The natural history study of Murray et al[28] does not support the ominous contentions of Bradford et al that "untreated kyphosis in a growing child may lead to progressive deformity, back pain, paraplegia, and cardiopulmonary failure".[4] The question is whether or not the results of the Murray et al review justify a nihilistic approach to the individual patient with Scheuermann kyphosis.

Although the available literature may lack strict scientific validity, the experiences of those who have authored papers on Scheuermann kyphosis with hundreds of patients can provide some guiding principles for treatment. The literature clearly reports a number of patients who presented complaining of significant pain, and surgical correction appears to be successful in alleviating the pain. Trunk deformity is often the primary concern of the patient, and its importance in our society and its role in driving people with roundback to seek treatment should be recognized.[44,45] Surgery appears to be the only method to reliably correct deformity and improve kyphosis to within the accepted normal ranges. The results of successful surgical correction are among the most dramatic in orthopaedic surgery, and Tribus has noted that the benefits of deformity correction achieved by surgery in adolescents and adults should not be underestimated.[44] These benefits are achieved, however, at considerable economic cost and with significant potential morbidity. The risks of surgical correction are clearly recorded in the literature, and must be considered and explained preoperatively to the patient. This type of surgery is technically demanding and should be undertaken only by highly trained spine surgeons, working in centers equipped to provide excellent technical correction and to handle the demands of perioperative care. Technological advances have changed the risk-benefit ratio in kyphosis surgery. The patient improvement in form, function, and self-esteem provided by corrective surgery, using thoracoscopic anterior release and fusion plus strong segmental posterior instrumentation and fusion, can be dramatically positive.

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■ Consensus Summary

The etiology of Scheuermann kyphosis (SK) is unknown. There is probably a strong hereditary pattern. It is a condition that by general agreement is defined by the wedging of more than 5° in three consecutive vertebrae. Scheuermann kyphosis patients generally present to physicians for concerns over deformity and pain. Natural history studies show that the pain generally subsides, but the deformity may be static or worsen.

Natural history studies for an extended period show no evidence of increased morbidity or increased mortality for patients with thoracic SK. The majority of cases never present for medical treatment. Most who present to a physician have mild deformity and minimal symptoms and do not require active treatment.

In patients with progressive deformity or severe deformities, treatment is advised. Some weak evidence exits that a brace can affect the deformity if applied during

growth, while the efficacy of other nonoperative measures—physical therapy and exercises—although widely prescribed have not been scientifically validated.

In more severe cases of SK, significant deformity can result. The acceptability of deformity and decisions referable to the surgical treatment of the deformity varies widely in different societies. The surgical correction of kyphosis, although feasible, is associated with significant risks. Newer generation instrumentation may improve deformity correction and lessen the risk of complications. Studies are needed to identify risk factors in progression.