REVIEW ARTICLE

Round and angular kyphosis in paediatric patients

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Abstract Structural kyphosis is a posterior convex deformity of the spine that may appear in childhood then worsen with growth, most notably during the pubertal growth spurt. The abnormal curvature may be smooth, defining round kyphosis, or may display a sharp angular pattern. Angular kyphosis is the more severe of the two forms. The main causes of round kyphosis are postural kyphosis and Scheuermann’s disease. The spontaneous outcome is favourable, and round kyphosis is well tolerated in adulthood. The treatment relies on orthopaedic methods in the overwhelming majority of cases. Surgery is reserved for severe rigid kyphosis in older children and for kyphosis responsible for refractory pain or neurological deficits. Surgical treatment carries a non-negligible risk of neurological, gastrointestinal, mechanical, and septic complications, which should be explained clearly to the family. Advances in contemporary posterior instrumentation have considerably limited the indications for anterior approaches. Many conditions may cause angular kyphosis, whose greater severity is related to a greater potential for progression and neurological impairment. Clinical investigations are in order to identify the cause and to plan the surgical strategy. Early surgery may be indicated, via a combined anterior and posterior approach. Anterior strut grafting, anterior or posterior osteotomies, or even vertebral column resections may be necessary to correct a major deformity.

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Kyphosis is a common reason for visits to paediatric orthopaedic clinics. The widespread belief among paediatricians and primary-care physicians that kyphosis is a benign deformity may lead to delays in obtaining specialised care for patients with progressive deformities.

Kyphosis is a symptom whose clinical features vary with the underlying aetiology. Establishing the diagnosis and identifying the cause is therefore crucial to ensure that optimal treatment is provided.

Definition

Kyphosis is a marked curvature of the spine in the sagittal plane, with a posterior convexity. Some degree of kyphosis is normal at the thoracic and sacral spinal segments. According to the Scoliosis Research Society classification system, the curvature in the sagittal plane is normally smooth and comprised between 20° and 45°. In a recent French and Canadian study in 341 normal individual, the mean thoracic kyphosis angle in children was 44 [1].

Physiological kyphosis is crucial to the sagittal balance of the spine, which has generated interest among many research groups in France and elsewhere [2,3].
Anatomic patterns of kyphosis

Kyphosis exists as two distinct types, round and angular. Two other patterns that deserve individualization are kyphosis associated with scoliosis, whether hyperrotatory or junctional, and olisthetic kyphosis; their treatment is a component of the overall management of the underlying condition and, consequently, they will not be discussed in this conference.

Round kyphosis

Round-back is the most common and best tolerated pattern of kyphosis and is often overlooked. There is a large-radius smooth curvature involving a large number of vertebrae. The most common location is the thoracic or thoraco-lumbar spine. Most patients have no other abnormalities. Round kyphosis is usually flexible and reducible during childhood but can evaluate to a rigid deformity during adolescence.

Angular kyphosis

Angular kyphosis is far more conspicuous, regardless of its location, as a sharp angle involving a small number of vertebrae disrupts the normal spinal curvature. Angular kyphosis is less frequent but more serious than round kyphosis. Progression may occur during growth and prompt treatment is required.

Angular kyphosis may be stable or unstable

In stable angular kyphosis, the abnormality involves a small number of vertebrae exhibiting severe deformities, as well as the intervening disks, which may be more or less complete depending on the cause. The capsules, ligaments, facet joints, and posterior part of the vertebral body are intact.

Unstable angular kyphosis may be caused by trauma or congenital deformities. The risk of neurological compromise in this form of kyphosis is of concern.

Congenital kyphosis is related to severe local and regional vertebral malformation that must be diagnosed at birth. Vertebra hypoplasia or aplasia results in loss of spinal alignment due to an abrupt step-off between two vertebrae, with focal kyphosis that is often very marked (Fig. 1).

Post-traumatic kyphosis is also a severe deformity that involves the three columns of the spine. This form of kyphosis occurs after a high-energy trauma and requires immediate treatment.

Clinical work-up

The clinical interview collects important information such as the date of onset of the deformity, whether progression has occurred over time, the presence of pain, the treatments used to date, and any other health problems in the patient or family.

The patient should be examined undressed in the standing position, or the seated position if needed, then bent forward. The spine should be assessed from the front, back, and sides. The shape of the kyphosis should be recorded, as well as whether scoliosis is present also. Complete disappearance of the deformity when the child is asked to stand up straight indicates postural kyphosis or simple slouching.

The severity of the deformity is assessed by measuring the sagittal distances from the plumbline of C7. The C7 plumbline is normally tangent to T6 and S1 and the cervical and lumbar distances are equal to about 3 cm. These two distances are increased in patients with kyphosis, in whom the C7 plumbline is no longer tangent to the sacrum.

Pelvic parameter should be evaluated, as well as lower limb alignment, i.e., the presence of overextension or permanent flexion of the hips or of permanent flexion of the knees. Reducibility of the kyphosis can be evaluated by suspending the child or having the child lie supine on a bolster placed under the apex of the deformity.

A detailed neurological evaluation is mandatory. Careful attention should be given to the deep tendon reflexes; superficial abdominal reflexes; and presence of hypertonia, sensory abnormalities, or altered sphincter function. The skin should be examined for café-au-lait spots and midline abnormalities (tuft of hair, angioma, lipoma, or coccygeal dimple). Joint laxity should be looked for. Any facial abnormalities should be recorded, as well as hydrocephalus, foot deformities, and acromegaly.

Investigations

In patients with marked kyphosis, full-length antero-posterior and lateral radiographs of the spine should be obtained in the upright position. The external auditory meatus and femoral heads should be visible. Low-dose radiographs obtained using the EOS™ system enable a good analysis of overall sagittal balance.

A lateral radiograph obtained under traction or with the patient lying supine on a bolster placed under the apex of the curvature provides information on the reducibility
of the deformity. A determination of bone age (on a hand radiograph) indicates how much growth remains to occur.

Magnetic resonance imaging of the spinal cord and spine allows an assessment of the cervico-occipital junction; spinal canal diameter at the apex of the deformity; and impingement on the spinal canal of bone structures, disc material, or tumour tissue. Spinal cord structure can be assessed and syringomyelia or congenital malformations of the spinal cord identified. An intra- or extra-canal tumour or dural ectasia should be looked for.

Computed tomography of the spine provides additional information on any bone abnormalities antedating or caused by the kyphosis. Three-dimensional reformation improves the assessment of bone morphology and relationships and helps to plan the surgical strategy.

Depending on the cause and possible treatment options, other specific investigations may be obtained, such as lung function testing, urodynamic assessment, a somesthetic evoked potential recording, an upper gastrointestinal contrast study, a spinal cord arteriogram, echocardiography, ultrasonography of the kidneys, an intradermal tuberculin test, or other investigations.

**Principles of treatment**

Several orthopaedic and surgical treatments are available and the strategy should be tailored to each individual patient.

**Orthopaedic treatment**

Orthopaedic treatment is indicated for round kyphosis of less than $65^\circ$ that is still reducible in a child who has at least 1 year of remaining growth. Orthopaedic methods may also be used in some patients with angular kyphosis, as a preliminary or addition to surgical treatment.

Physical therapy to improve posture aims at strengthening the trunk muscles and stretching the hamstring muscles. Physical therapy may serve to alleviate the pain.

Bracing is the mainstay of the orthopaedic treatment of kyphosis. The goal is to correct and to stabilise the deformity. The brace is effective if it increases the flexibility of the deformity and decreases the curvature by more than $15^\circ$. The Milwaukee brace and the kyphosis bivalve brace are the most widely used devices in patients with kyphosis. A cast may be fashioned to correct a marked and rigid kyphotic deformity before the use of a brace or to ensure postoperative immobilisation after epiphysiodisectomy in a young child. When there is no instability or risk of spinal cord compression, the preferred approach in patients with severe and markedly rigid kyphosis is gradual correction of the deformity to facilitate the surgical treatment, decrease the risks of surgery, and improve post-surgical outcomes.

**Surgical treatment**

The surgical treatment of severe kyphosis, most notably in angular forms, can include two steps, one via an anterior and the other via a posterior approach.

**Anterior surgery**

Strut grafting is used in patients with angular kyphosis. Tibial strut grafts are implanted in a palisade configuration from back to front (Fig. 2). The concavity of the deformity is thus filled with bone, producing a construct of good mechanical stability.

In patients with round kyphosis, inlay grafting with the rib removed in the surgical approach can be performed. After excision of the discs, a longitudinal groove is fashioned along the lateral aspect of the vertebral bodies and the rib graft is then implanted in the groove. For patients who have irreducible kyphosis with anterior fusion (kyphosis due to congenital defects, infection, or previous surgery), one or more anterior vertebral osteotomies may be needed to disrupt the fusion bridges and allow reduction of the deformity. In marked angular kyphosis with spinal cord compression, decompression or even spinal cord transposition may be needed before bone grafting can be performed. Finally, the anterior approach can be performed by video-assisted thoracoscopic surgery to minimise morbidity and improve the cosmetic outcome [4].

**Posterior surgery**

One option is posterior epiphysiodesis, in which the neural arches at the apex of the curvature are fused to ensure gradual correction of the kyphosis as growth of the anterior spine proceeds. Epiphysiodesis can be performed in children younger than 5 years who have angular kyphosis.

Posterior arthrodesis is used in combination with instrumentation that provides long coverage, preferably with hooks in the proximal half and screws in the distal half. Correction is achieved either via a lever manoeuvre performed during insertion of the rods and completed by compression on either side of the apex of the deformity or via in situ bending of the rods [5]. In older children with very
round deformities, osteotomies of the fused neural arches or transpedicu-
lar osteotomies can be performed before the instrumen-
tation step. Advances in posterior instrumentation
have been reported to allow vertebral column resection via
the posterior approach alone to achieve single-stage,
targeted, and focalised correction of severe spinal deformities
[6]. The most widely used implants are hooks proximally and
pedicul ar screws distally. However, surgeons are increas-
ingly using screws for the entire construct. Metal wires or
polyester bands may be appropriate in some cases, as well
as plates or anterior spacers combined with bone grafts in
the event of vertebral column resection. The choice depends
on each individual case and on the habitus of each surgeon.

After vertebral arthrodesis with instrumentation, early
complications include pulmonary, neurological, gastroin-
testinal, infectious, and mechanical complications. Delayed
complications consist of non-union, implant fractures, loss
of correction, junctional kyphosis, and late osteoarthritis
under the fused segment.

Aetiologies and therapeutic indications

Kyphosis can occur in a large number of conditions. Without
attempting to provide an exhaustive list, we will discuss the
main causes of kyphosis, with the corresponding treatment
options.

Round kyphosis in children

Children may present with postural kyphosis or simple
slouching. The deformity can be corrected voluntarily by the
patient or disappears spontaneously in the supine position.
The paediatrician or family physician should recommend
proper posture while sitting, together with regular sport-
ing activities. A physical examination should be performed
every 6 months and radiographs once a year to enable
early referral, if needed, to a rehabilitation physician or
orthopaedic surgeon. If the deformity persists or worsens,
the orthopaedic surgeon starts treatment with a Spine-
Straight device or a night time brace.

Developmental kyphosis is a common cause of kyphosis.
Scheuermann’s disease is the most common form [7]
and affects 4 to 8% of all children, with a predominance in
boys [8,9]. The deformity is usually located at the thoracic
spine (type 1); thoraco-lumbar and lumbar (type 2) forms
are far less common. The cause of Scheuermann’s disease
is unclear. Abnormal terminal ossification of the vertebral
bodies results in vertebral wedging in type 1 Scheuermann’s
disease. In type 2, which affects the thoraco-lumbar or lum-
bar spine, intra-osseous disc herniation may occur, without
wedging. The deformity may be associated with persistent
pain. In a tiny minority of very severe forms, neurological
signs may develop.

Radiographs show irregular endplates, wedging of at least
three adjacent vertebral bodies with marginal impaction,
and geodes known as Schmörl’s nodes due to the herniation
of disc material into the abnormally fragile vertebral bone.
Selection of the best treatment depends chiefly on the age
of the child, the rigidity of the deformity, the location and
number of involved vertebra, and presence of refractory
pain. Type 2 disease, affecting the thoraco-lumbar or lumbar
spine, usually produces moderate angular deformities but is
more often responsible for pain related to intra-osseous disc
herniations. Orthopaedic management is the rule. In a few
cases, neurological symptoms may arise, requiring surgery
to release the spinal cord followed by posterior fusion with
instrumentation. In type 1 disease affecting the thoracic
spine, the deformity is rarely marked in early childhood and
is always flexible and amenable to orthopaedic treatment.
As soon as the curvature exceeds 50°, full-time use of a brace
is in order. A thoracic-lumbar-sacral orthosis or Boston brace
has been advocated instead of a Milwaukee brace [9]. Phys-
ical therapy may be used in addition to bracing but is never
sufficient to correct an established kyphotic deformity.

In the US, the recommended duration of orthopaedic
treatment is 18 months. We prefer to continue the treat-
ment until growth is complete, to avoid a recurrence of the
defor mity (Fig. 3a and 3b) [9,10]. There is widespread agree-
ment that orthopaedic therapy is effective in adolescents
with flexible kyphosis or a Risser stage lower than 3; the
Milwaukee brace is often poorly accepted by adolescents
and can be replaced by a kyphosis bivalve brace [10]. In
rigid deformities, a series of corrective casts may be useful
initially.

Studies have reported 10° to 20° of loss of correction
after orthopaedic treatment discontinuation in at least 30%
of cases [8].

The indications for surgical treatment are not clearly
defined in the literature [11]. In most English-language pub-
llications, the criteria used to indicate surgery were a greater
than 70° curvature in kyphosis of the mid-thoracic spine,
documented negative cosmetic and psychological effects,
and pain refractory to non-surgical therapy [9,12,13]. In
France, the indications are more restrictive given the benign
character and natural history of the deformity (Murray),
as well as the risks associated with surgical management
[14,15]. Surgery is thus reserved for marked, rigid, painful
deformities in older children and for patients with neurological manifestations.

In young children below Risser stage 2 or 3 with deformities of at least \( 70\degree \), isolated posterior fusion is adequate. In this situation, the subsequent growth of the vertebral bodies is sufficient to fill the modestly sized anterior gaps created by the correction of the kyphosis (Fig. 4a and b).

At the end of the growth period, posterior surgery alone is being increasingly recognised as sufficient given the improvements made in the efficiency and strength of last-generation segmental instrumentations. An additional anterior step is reserved for patients with deformities greater than \( 100\degree \) or anterior bony fusion [12,16–18]. The anterior step can be performed by video-assisted thoracososcopic surgery [4]. We advocate a preparatory phase in patients with deformities greater than \( 90\degree \), to test the gastrointestinal and neurological tolerance of the correction [10]. Anterior fusion is usually performed over a shorter segment than posterior fusion, i.e., over five to seven discs, usually two or three on either side of the apex. Any anterior ossifications must be completely excised. The posterior fusion should be sufficiently long and provide enough coverage to prevent the development of a secondary kyphotic deformity at the junction between the fused segment and the unfused segment. We usually end the instrumentation distally at the vertebral body located just above the first horizontal disk on the radiograph taken in hyperextension on a support or in the standing position. In the US, the fusion is ended distally at the vertebra above the first disc that is open anteriorly and no attempt is made to decrease the angle below \( 50\degree \), in order to avoid spinal malalignment and postoperative junctional kyphosis [19].

Thus, the objective of surgery should consist not only in correcting the kyphotic deformity, but also in restoring the global balance of the body by adjusting the amount of correction to the sagittal parameters of the adjacent segments, at the neck, lumbar spine, and pelvis. A preoperative evaluation of these parameters on EOS\textsuperscript{TM} images can prove valuable for estimating the amount of correction that is appropriate.

**Kyphosis due to congenital malformations**

Kyphosis may be caused by congenital defects in vertebral formation or segmentation, which are often diagnosed at birth or even prenatally (Fig. 5). Congenital kyphosis is usually angular and progressive, as a growth imbalance occurs between the anterior and posterior portions of the abnormal
region. Consequently, closely spaced follow-up visits are in order.

Bracing is reserved for small-angle deformities with limited progression. However, bracing can also be used as an adjunct to surgical treatment.

During the growth period, the treatment indications depend on the rate of progression of the deformity. Rapid progression indicates a need for immediate surgery, particularly in the case of angular kyphosis.

In children younger than 5 years, surgical posterior epiphysiodesis without instrumentation extending proximally and distally one or two levels beyond the kyphotic spinal segment is widely advocated and ensures gradual correction of the deformity as growth proceeds [20, 21]. In children aged 7 to 12 years, posterior arthrodesis with instrumentation over a short segment is indicated [22]. When the deformity worsens only during the pubertal period, posterior arthrodesis with instrumentation and broad coverage is in order to correct the deformity at the levels adjacent to the congenital defect. In some patients with anterior block vertebrae diagnosed at an early age, anterior separation osteotomies can be followed immediately by posterior compression fixation without fusion, at a very young age (Fig. 6a and b).

In older children who were not treated in time, surgery involves anterior release and osteotomy followed by posterior correction and fusion with instrumentation (Fig. 7a and b).

In some patients with neglected block vertebrae or progressive anterior vertebral ossifications responsible for completely rigid kyphotic deformities, transpedicular osteotomies via the posterior approach may be in order (Fig. 8a and b).

Anterior "desepiphysiodesis" (i.e., excision of the bony bridge) has been suggested to restore growth between the vertebral bodies [23]. Lumbar and lumbosacral agenesis and congenital dislocation of the spine result in angular kyphosis with luxation. Neurological impairments may be noted at birth or may develop later on. Consequently, a radiological evaluation must be obtained at first presentation. These forms of kyphosis are surgical emergencies that require stabilisation by combined anterior and posterior fusion.

For kyphosis associated with spina bifida, there is general agreement that vertebral resection at the apex of the deformity should be followed by sliding posterior instrumentation without fusion, from the upper thoracic spine to the
of neurological compromise. Stabilisation must be achieved using circumferential fusion, with or without instrumentation depending on the patient’s age [25]. In some forms of skeletal dysplasia such as Morquio syndrome or achondroplasia, the dystrophy may predominantly affect a few rostrum-shaped vertebrae, producing an angular kyphotic deformity that may threaten the spinal cord, which is already jeopardised by the constitutionally narrow spinal canal. During the growth period, the treatment in moderate forms relies chiefly on orthopaedic methods. In patients with severe deformities or neurological compromise, anterior vertebral fusion with tibial strut grafting followed by posterior fusion should be performed after gradual correction of the deformity. Care should be taken to identify any neurological manifestations such as increased deep tendon reflexes or lower limb spasticity, which may indicate incipient spinal cord damage at the apex of the deformity (Fig. 10a–d) [26,27].

Kyphosis due to paralysis

Kyphosis may develop in patients with a variety of neurological conditions such as paraplegia due to trauma, a tumour, or myelitis; encephalopathies; central or peripheral neuropathies; myopathies; and other diseases. The vertebral body deformities long remain modest and the kyphosis fairly easy to reduce, even in advanced forms. The spinal collapse is well corrected by bracing during childhood but surgery must be performed in adolescence. The internal fixation serves as an internal spinal guide and substantially improves comfort of the patient and family. Distal forms of kyphosis may lead to compensatory thoracic lordosis that should be taken into account during the correction to avoid inducing posterior malalignment of the spine. Because the muscles are paralysed, posterior fusion with instrumentation extending to the pelvis must be performed, as generally advocated in the literature (Fig. 11a and b) [28].

Post-traumatic kyphosis

Acute traumatic injuries of the spine in children with or without neurological manifestations should be treated by casting followed by bracing for at least 2 years if the deformity is moderate and stable and by anterior and/or posterior fixation in angular or unstable deformities, with spinal cord decompression if needed. There is a general consensus in the literature that reduction and posterior fixation without grafting is the appropriate strategy in forms with limited angulation [29].

When kyphosis occurs as a sequela, the spinal malunions require combined anterior and posterior surgery, as described above for kyphosis due to congenital malformations.

Kyphosis due to infection

Discitis due to pyogenic bacteria or to the Koch bacillus may result in destruction of the disc and vertebral body, thereby inducing kyphosis. At the early stages, conservative orthopaedic treatment combined with appropriate
pharmacotherapy may ensure satisfactory reconstruction. Later on, however, the kyphosis tends to become irreducible.

Among infections, tuberculous discitis in young children is the most common cause of kyphosis, as several discs are usually involved. Spinal cord damage due to compression at the apex of the deformity is exceedingly rare in children, even those with severe deformities, and often produces manifestations only very late in the course of the disease. Initially, surgery is indicated in the event of spinal cord compression, which is usually due to an anterior epidural abscess. Laminectomy is not indicated, as it fails to release the anterior compression and may induce severe spinal instability. An anterior approach should be used to allow spinal cord decompression, removal of the abscess, and strut grafting. Then, appropriate antibiotics should be given and the spine should be immobilised by a cast or by posterior fusion with instrumentation [30].

In most cases, however, in the absence of spinal cord compression or when the abscess is controlled by the antibiotic therapy, posterior surgery alone may be sufficient. At the stage of residual lesions, surgery may be needed in the event of gradual progression of the kyphotic deformity or of spinal cord complications.

In the absence of neurological complications, the treatment relies on anterior strut grafting combined with posterior fusion with instrumentation. Complete rest must be instituted as an emergency measure in patients with neurological manifestations. If the radiographs taken in the supine position on a support indicate some measure of flexibility, gradual reduction of the deformity by traction on the head in bed or by a lengthening cast usually improves the neurological manifestations. Stabilisation of the spine is then achieved by combined anterior and posterior fusion. If the kyphotic deformity is irreducible or traction has no effect or worsens the neurological symptoms, anterior spinal cord decompression by vertebral resection is required when the neurological impairments are significant. This decompression procedure is the first step of anterior surgery and should be followed by grafting and posterior stabilisation.

**Kyphosis due to tumours**

Spinal tumours are rare in paediatric patients but can cause progressive kyphosis due to collapse of the anterior part of
the spine, with preservation of the posterior vertebral wall for a variable period. Lateral or rotational displacements do not occur until the tumour involves or destroys the pedicle and facet joints.

Any primary tumour or metastasis that destroys these components of the spine can cause kyphosis. In Langerhans cell histiocytosis, kyphosis may antedate the development of vertebra plana. Kyphosis in a patient with a spinal tumour should always prompt an evaluation for potential instability, which may lead to dural sheath compression at the apex of the deformity.

Thus, the local treatment of these tumours should take into account not only the need for correcting the malalignment (the kyphosis), but also the need for restoring the mechanical strength of the anterior spine by interbody grafting [31].

Iatrogenic kyphosis

Extensive laminectomy that is not followed by appropriate reconstruction and adequate postoperative immobilisation can result in instability of the posterior spine, which inevitably causes progressive kyphosis. The prevention of kyphosis involves performing laminoplasty instead of laminectomy and ensuring prolonged postoperative immobilisation by a brace. Combined anterior and posterior grafting is usually needed [32,33].

Prolonged radiation therapy may decrease the strength of the vertebral bone tissue, allowing the gradual development of a kyphotic deformity. This complication has become exceedingly rare since the introduction of improved treatment methods for tumours. When surgery is performed to treat radiation-induced kyphosis, the combination of paraspinal muscle wasting and skin fragility may hinder coverage of the fixation material, whose prominence should be minimised. Anterior fusion in good-quality underlying bone is required to compensate for the poor quality of the posterior fusion and fixation. The posterior fusion should extend far beyond the radiation field boundaries and the fixation material should be secured to good-quality bone.

Strategic errors in the treatment of abnormal spinal curvatures (excessively short construct or inappropriate positioning of the boundaries) may lead to the development of kyphosis at the junction between the instrumented and non-instrumented regions. In this case, further surgical treatment is needed to extend the construct. Iatrogenic kyphosis located in the middle of a fusion zone is completely irreducible. Surgical correction requires osteotomies of the previous graft, in one or more stages.

Conclusion

Kyphosis is a common spinal deformity in children and may be either round or angular. Kyphosis may progress with growth. Primary-care physicians should be able to establish the early diagnosis of a deformity that is becoming structural, to ensure the timely provision of treatment. Treatment may be in order at a young age or even on an emergency basis in patients with unstable deformities.

Surgical indications remain poorly standardised in older children with round kyphosis. In this situation, surgery should be reserved for severe forms responsible for pain, given the many possible adverse events and the good tolerance of the deformity in adulthood.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


