Assessment and management of adult spinal deformities

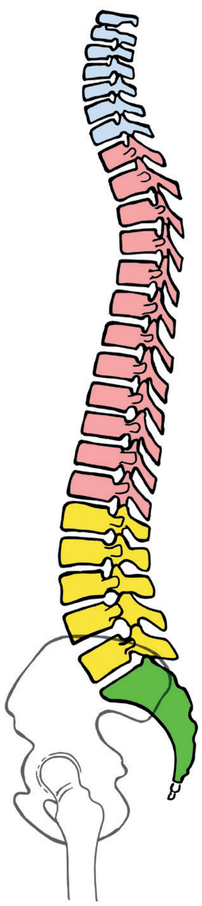
ABSTRACT

Adult spinal deformity is a complex condition, increasing in prevalence, and occurring in a patient population in which it poses unique challenges. This review provides an overview of adult spinal deformity with a particular focus on its clinical evaluation, radiological assessment and classification, reviewing the current literature and amalgamating this with the authors' clinical experience.

The normal adult spine has a series of anatomical curves in the sagittal plane that are critical for ambulation and forward gaze. There are no curves in the coronal plane. Disruption of this normal, physiological profile results in a spinal deformity. The current prevalence of spinal deformities is estimated to be as high as 68% in patients aged 70 years (Schwab et al, 2005; World Health Organization, 2015). It is therefore essential that all physicians who may interact with such patients have a basic understanding of this condition.

The development of the normal sagittal and coronal spinal profile seen in adults begins in utero. In the fetus the spine lies flexed like the letter C. This primary, kyphotic curvature of the spine is retained throughout life in its thoracic, sacral and coccygeal portions. However, in the cervical and lumbar spine secondary lordotic curves develop in order to support the head and trunk respectively (McMinn, 1995). Ultimately this results in a flexible lordotic cervical spine, a rigid kyphotic thoracic spine, a flexible lordotic lumbar spine and an anteriorly tilted pelvic-sacrococcygeal complex (*Figure 1*) (Legaye et al, 1998; Rose et al, 2009). There are normally no curves in the coronal plane.

Figure 1. Sagittal spine depicting primary thoracic and sacrococcygeal kyphosis (TK, SK) along with secondary cervical and lumbar lordosis (CL, LL).



Abnormal forward curvature in the sagittal plane, colloquially known as hunching, is termed hyper-kyphosis while excessive backward curvature is termed hyper-lordosis. Coronal plane deformities are known as dextro-scoliosis or levo-scoliosis, depending on whether the apex of the abnormal curve is right or left respectively. In adults, although coronal balance is important, abnormal sagittal balance has a more profound impact on a patient's symptoms (Daubs et al, 2013). In order to correct for an abnormal positive sagittal imbalance, with an anteriorly placed centre of gravity, the adult patient adopts a painful and fatiguing compensatory posture: the pelvis is tilted posteriorly, the hips extended, the knees flexed and ankles dorsiflexed (Roussouly and Nnadi, 2010). Unsurprisingly this pathological posture takes its toll on the adult

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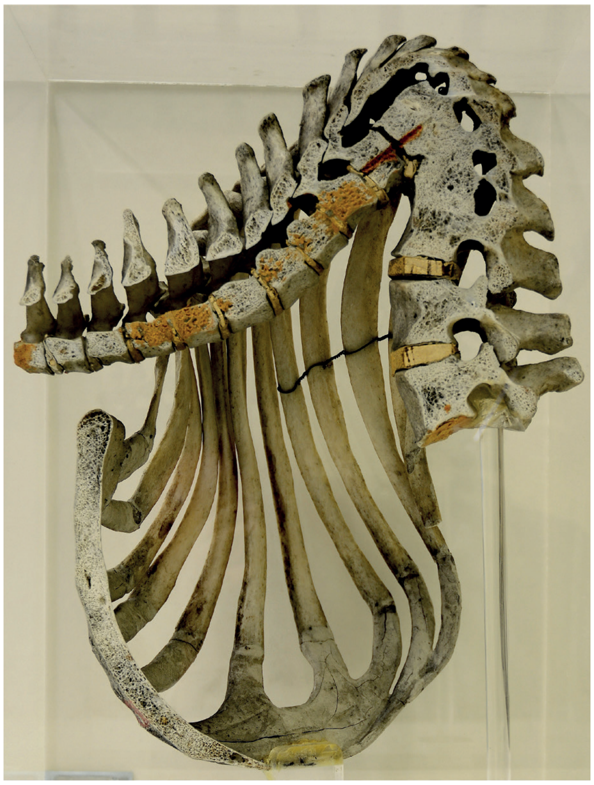
Figure 2. Severe thoracic kyphosis secondary to healed tuberculosis. A half skeleton of the trunk, showing deformity of the thorax owing to a sharp angular curvature in the lower dorsal region, which is partially compensated by a lumbar lordosis.



patient. As such, sagittal imbalance has repeatedly been shown to correlate with objective clinical scores including the Scoliosis Research Society-22 questionnaire, the Oswestry Disability Index and Short Form 36 (Glassman et al, 2005a,b; Yang et al, 2006). Indeed, in symptomatic patients, sagittal imbalance has a similar disabling impact to chronic diseases such as diabetes (Bess et al, 2016).

Aetiology

Adult spinal deformity can broadly be divided into four groups. The first group includes patients with pre-existing childhood deformities such as idiopathic adolescent scoliosis and Scheuermann's disease. These patients frequently present as young adults.

The second group has a spinal deformity that develops de novo in adult life, such as degenerative kyphoscoliosis. The average age of these patients is 60 years of age (Gupta, 2003).

The third group includes patients with an iatrogenic spinal deformity secondary to previous spinal surgery.

The fourth group includes patients with deformities secondary to systemic diseases such as ankylosing spondylitis, Parkinson's disease and tuberculosis (*Figure 2*).

Clinical assessment

Clinical history from a patient with adult spinal deformity should establish the onset and progression of the deformity. A rapidly progressing deformity may suggest an underlying neurological disorder such as Parkinson's disease.

A clear description of symptoms, if present, should be noted. When pain is present, specific questioning should ascertain the nature, timing, duration, aggravating factors, relieving factors and associated features. Sinister causes of back pain and deformity such as neoplasia, acute fracture or infection must be excluded. Analgesia use, family history, childhood illnesses and obstetric or gynaecological history, if relevant, should be explored. The psychological and social impact of deformity on the patient should also be noted.

Physical examination mandates assessing the undressed patient from in front, behind and from the side in the standing position. Skin changes such as café-au-lait spots, hairy patches, dimples in the skin and naevi may be signs of neurological abnormalities. Limb length discrepancy, general facial and truncal asymmetry should be noted. Particular attention should be paid to the patient's hips, knees and ankles as many patients adopt a compensatory posture to counter their spinal deformity. Gait is assessed and the level of the shoulders and pelvis should be noted. Asking the patient to bend forward (the Adam's test) may highlight prominence of the thoracic cage. Spinal and/or sacroiliac joint tenderness should be documented as this may be a consequence of an underlying inflammatory condition such as ankylosing spondylitis. A complete neurological examination is essential.

Radiological assessment

Adult spinal deformity is classically evaluated with standing full-length 36-inch posterior-anterior and lateral radiographs, colloquially known as scoliosis films (*Figure 3*). Posterior-

Figure 3. Standing full-length scoliosis films. **a.** Posterior-anterior and **(b)** lateral radiographs of a patient with thoracic hyper-kyphosis and compensatory lumbar lordosis.

anterior radiographs are preferred to anterior-posterior radiographs to limit the dose of radiation to the chest. Radiographs should include the whole spine, entire rib cage, iliac crest and hip joints. They should be performed with the patient's knees in full extension and shoulder width apart if possible. A standing block should be used if a significant leg length discrepancy (2 cm or more) is present. When identifying a vertebral level, the authors advocate counting caudally from the second cervical vertebrae as counting from the presumed fifth vertebrae raises the possibility of not appreciating lumbosacral variation (Paik et al, 2013).

Sagittal balance

Sagittal balance is typically assessed using lateral radiographs that include the whole spine and femoral heads. Sagittal balance should be assessed first globally and then regionally.

Global sagittal assessment involves dropping a vertical plumb line from the centre of the body of C7. If this line falls in front of the sacral promontory, the patient is described as having positive sagittal balance, and if the plumb line falls behind the sacral promontory, the patient is described as having negative sagittal balance. The C7 plumb line and the postero-superior corner of S1 is termed the sagittal vertical axis. It is thought that a positive sagittal vertical axis of 5 cm or more is pathological (Harding, 2009).

A more detailed regional assessment of sagittal balance is then conducted by quantifying thoracic kyphosis, lumbar lordosis and three pelvic parameters.

Thoracic kyphosis is represented by the angle subtended by lines parallel to the cephalad endplate of T4 and caudad endplate of T12, which normally varies between 20 and 50°.

Lumbar lordosis is the angle subtended by lines parallel to the cephalad endplate of L1 and caudad endplate of L5. This angle typically ranges from 31 to 79° (Roussouly and Nnadi, 2010) (*Figure 4*).

Pelvic parameters

Pelvic incidence represents an angle subtended by a line drawn from the centre of the S1 endplate to the centre of the femoral head and a second line drawn perpendicular to the line parallel to the superior endplate of S1. Pelvic incidence is a fixed angle in adulthood and measures approximately 52° with a range from 34 to 84° (Van Royen et al, 2000).

Pelvic tilt describes the rotation of the pelvis around the femoral head and it is the angle between a line from the centre of the femoral head to the centre of the midpoint of the S1 endplate and a second vertical line originating from the centre of the femoral head. Pelvic tilt is normally 12° with a range of 5 to 30° (Van Royen et al, 1998). Pelvic tilt does vary during adulthood and a high pelvic tilt is often adopted to compensate for a kyphotic spinal deformity.

Sacral slope is the angle between the superior endplate of S1 and the horizontal axis. Sacral slope is approximately 40° with a range of 20 to 65°. Sacral slope too can vary in adulthood (Van Royen et al, 2000).

There is a geometrical relationship between these angles: pelvic incidence = pelvic tilt + sacral slope (*Figure 5*).

Figure 4. Sagittal balance demonstrating sagittal vertical axis (SVA), thoracic kyphosis (TK) and lumbar lordosis (LL) measurements.

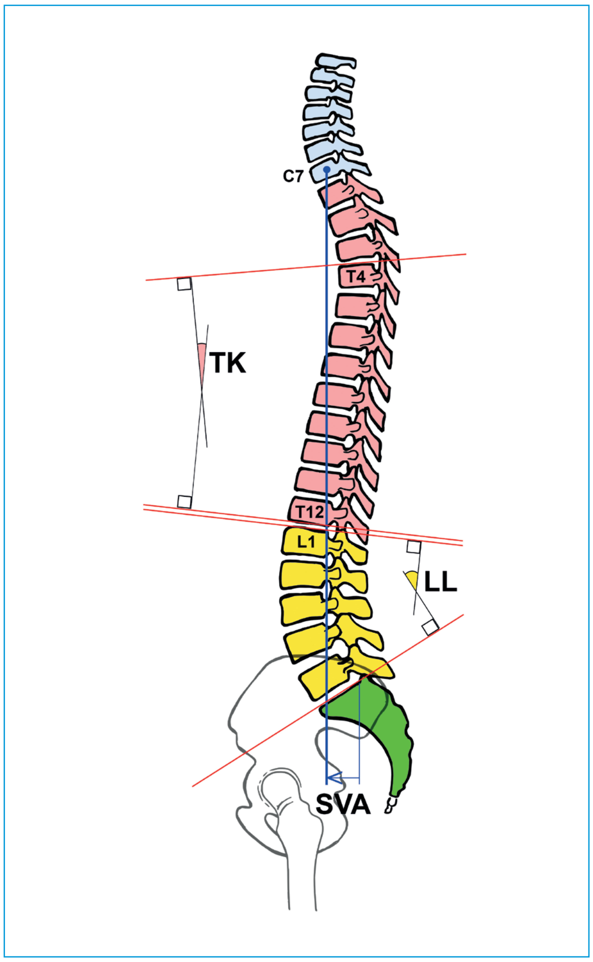


Figure 5. Pelvic parameters. Pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS).

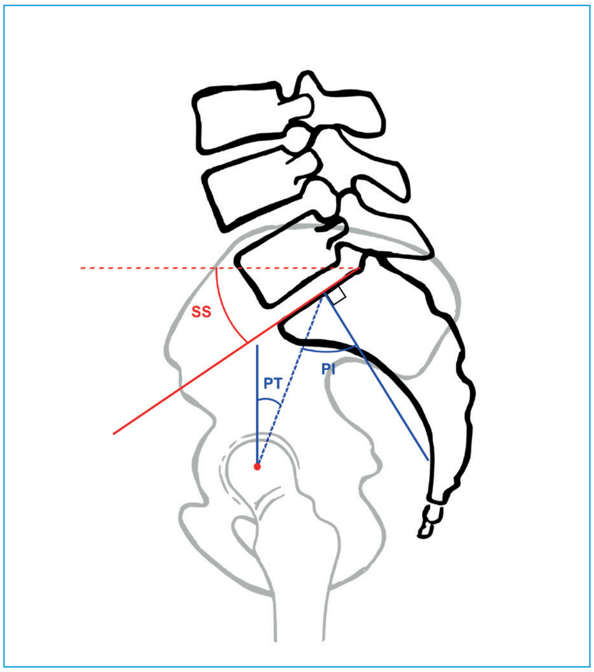
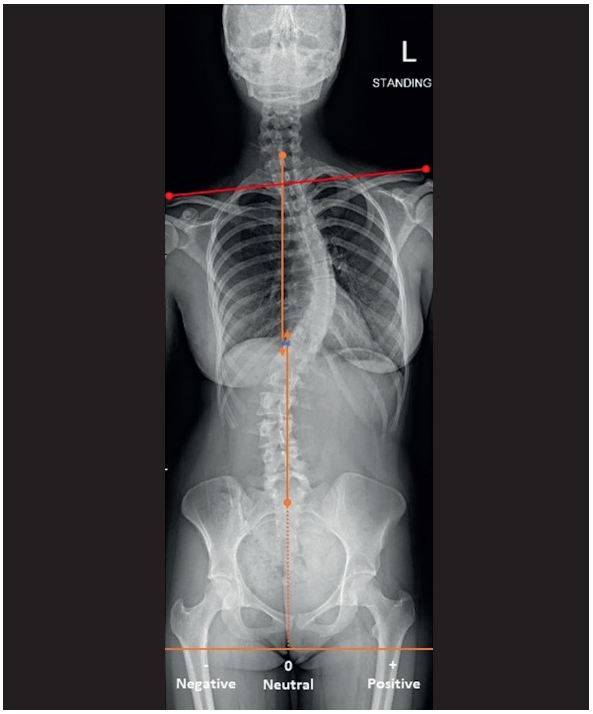


Figure 6. Global coronal balance and clavicle asymmetry. A patient with a slightly negative (blue line) global coronal balance and clavicle asymmetry (red line).



By quantifying each of these regional parameters the physician can determine whether, by way of example, a positive sagittal profile is the result of excessive thoracic kyphosis or loss of lumbar lordosis.

Further lateral imaging includes bolster views, taken with the patient supine on a bolster. This allows the surgeon to ascertain whether a sagittal plane deformity is flexible.

In a manner similar to the assessment of sagittal balance, the authors suggest first quantifying global coronal imbalance and then assessing regional coronal imbalance using posterior-anterior radiographs of the whole spine.

Coronal balance

Global coronal imbalance can be quantified by measuring the distance between a plumb line from the centre of C7 and a vertical line from the centre of the sacrum, the central sacral vertical line. This distance is usually less than 1 cm (Qiu et al, 2009) At this time, also assess shoulder asymmetry; this is measured by the clavicle angle, an angle obtained between a line connecting the distal aspects of both clavicles and the horizontal axis (Malfair et al, 2010) (*Figure 6*).

Having assessed the patient's global coronal imbalance, his/her regional coronal imbalance can now be assessed by first quantifying the number of coronal curves present. The central sacral vertical line is drawn and the number of apical vertebra on either side of the line is identified. The apical vertebra is the most laterally displaced vertebra from the vertical axis on the posterior-anterior film. Each apical vertebra represents the apex of a distinct coronal curve.

Coronal curves can be described according to the direction of the curve: levo-scoliosis (apex to the left) or dextro-scoliosis (apex to the right). Coronal curves can also be described according to the affected spinal region: cervical, cervical-thoracic (apex between C7 and T1), thoracic, thoracolumbar (apex between T12 and L1) or lumbar (Lenke et al, 2001).

Cobb angle and rotation

Having described the direction and location of each curve, the curve needs to be quantified by measuring the Cobb angle. Each curve has a superior (cephalad) and inferior (caudad) end vertebra. The Scoliosis Research Society (2000) defines the superior end vertebra as the first vertebra in the cephalad direction from a curve apex whose superior endplate is maximally tilted toward the concavity of the curve. The caudad is the first vertebra in the caudad direction from a curve apex whole inferior endplate is maximally tilted toward the concavity on the curve. The angle subtended between the superior endplate of the cephalad end vertebra and the inferior endplate of the caudad vertebra is the measure of the curve magnitude most commonly known as the Cobb angle. The major curve has the largest Cobb angle and other curves are minor curves.

Spinal deformities are three-dimensional and so it is important to also assess for abnormal vertebral rotation. Orientation of the cortex of the pedicles in posterior-anterior radiographs can be used in this regard. As described by Nash and Moe (1969), the degree of rotation is greater when there is greater displacement of the pedicle cortex in relation to the centre of the vertebra body (Perdriolle and Vidal, 1987) (*Figure 7*).

Further imaging

Further imaging includes lateral bending radiographs to determine whether a coronal curve is structural or non-structural, rigid or flexible. As with the previously described bolster views, these radiographs are typically performed by the spinal deformity surgeon when assessing treatment options.

Additional imaging modalities include magnetic resonance imaging and computed tomography. Magnetic resonance imaging can be performed to assess for stenosis, facet joint hypertrophy and degenerative disc disease. Magnetic resonance imaging is also invaluable in helping to exclude pathologies such as neoplasia and infection. Computed tomography with or without myelography can be performed not only when magnetic resonance imaging is contraindicated but also when better visualization of bony anatomy and assessment of rotational deformity is required. Computed tomography scans are particularly useful in assessing the extent of previous decompression, the position of spinal implants and the presence of bony fusion in iatrogenic deformities. Dual-energy X-ray absorptiometry is also recommended in patients at risk of osteopenia or osteoporosis (Youssef et al, 2013).

Classification

The ideal classification system in adult spinal deformity should:

1. Objectively describe the deformity aiding communication between physicians and researchers, with minimal observer variability
2. Be clinically relevant thereby facilitating decision making when planning patient care
3. Allow physicians to accurately measure the impact of interventions.

The development of classification systems in adult spinal deformity reflects in part our evolving understanding of this complex condition. Initially, the classification systems used were those developed primarily for paediatric spinal deformities such as the King–Moe classification and the Lenke classification systems. More recently, classification systems have been developed specifically for adult spinal deformities, building on earlier experiences with paediatric deformity classification systems.

The Aebi system classifies deformities according to aetiology and is a useful aide memoire, reminding the physician to identify those curves that are secondary to other pathologies such as metabolic bone disease (Aebi, 2005) (*Table 1*). The Bridwell classification, on the other hand, evaluates the flexibility of a kyphoscoliosis and helps the surgeon decide what type of osteotomy, if any, is required (Booth et al, 1999) (*Figure 8*). Finally, the Scoliosis Research Society-Schwab adult spinal deformity system classifies the curve according to its radiological appearance, using those radiological parameters that are known to correlate with quality of life (*Figure 9*). By using the Scoliosis Research Society-Schwab adult spinal deformity classification pre- and postoperatively a surgeon can measure the clinical and radiological impact of surgery (Schwab et al, 2007; Smith et al, 2013).

Basic principles of adult spinal deformity management

An increasingly active and aging population has resulted in an increase in the number of adult patients seeking care for their spinal deformities. The decision between operative and non-operative management depends on a number of issues including pain, reduction in function, progression of deformity, cosmesis and the patient's general health.

Non-surgical treatment is the first-line option for most patients. It includes use of pharmacological agents such as non-steroidal anti-inflammatory drugs, opiates and medications such as amitriptyline, gabapentin and pregabalin (Youssef et al, 2013). Further non-operative measures include physical therapy and yoga to improve core strength. Chiropractic manipulation and bracing, although controversial, may offer temporary relief. Targeted epidural injections, nerve root blocks and facet joint injections also act as both diagnostic and therapeutic tools (DePalma and Slipman, 2008).

Patients presenting to specialist surgeons have usually already had a trial of non-operative measures. Suggested surgical indications include intractable back or radicular leg pain despite non-operative measures, documented curve progression, cardiopulmonary compromise, development of neurological symptoms, and declining

Figure 7. Pedicle method of assessing vertebrae rotation. The vertebral body is divided into six segments and the position of the pedicle on the convex side within the segments determines rotation.

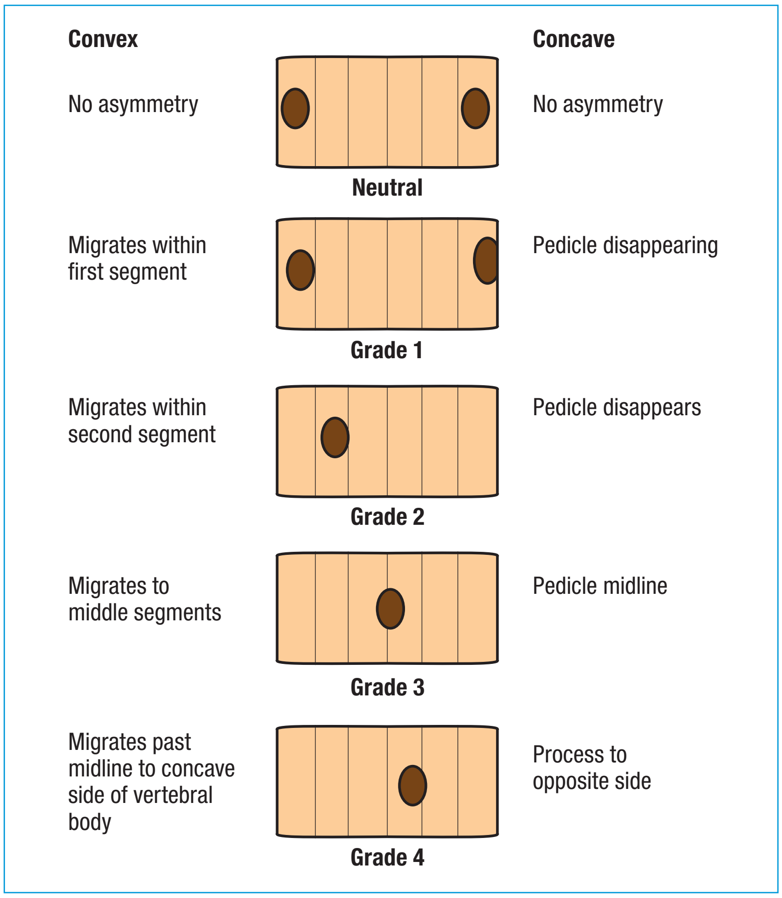


Table 1. Aebi's aetiological classification

Type	Description
1	Primary degenerative 'de novo' scoliosis Develops after skeletal maturity Results from asymmetric disc and facet joint degeneration There are minimal structural vertebral deformities Typified by lower lumbar curves
2	Progressive idiopathic scoliosis in adult life It can involve the cervical, thoracic and lumbar spine Secondary degenerative changes are superimposed on the preexisting deformity as the patient ages
3a	Secondary degenerative scoliosis following idiopathic, neuromuscular or congenital scoliosis or in the context of a pelvic obliquity secondary to hip pathology, leg-length discrepancy or lumbo-sacral anomaly
3b	Secondary degenerative scoliosis secondary to metabolic bone disease (mostly osteoporosis) combined with asymmetric degenerative disc and/or vertebral fractures

Adapted from Aebi (2005)

Figure 8. Bridwell algorithm for osteotomy type based on the character of the sagittal deformity. Patients with type I imbalance can maintain balance by hyperextending segments above and below the deformity. Hyperextending segments to maintain balance does not occur in type II imbalance. From Bridwell (2006).

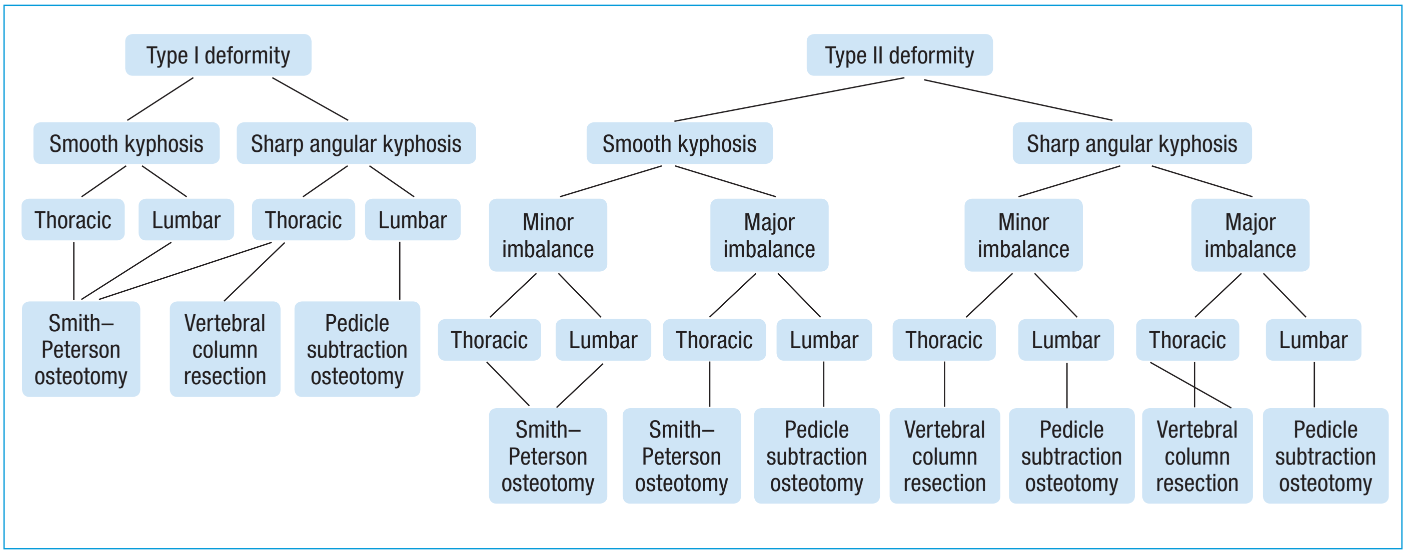
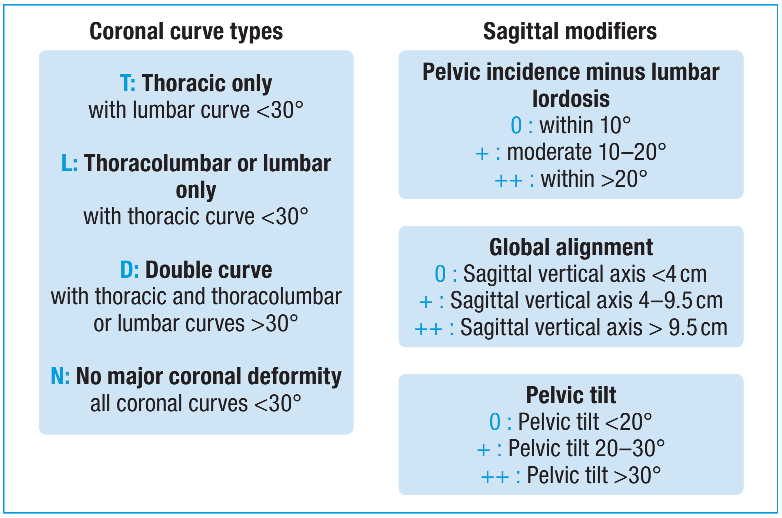


Figure 9. Scoliosis Research Society-Schwab adult spinal deformity classification. Adapted from Schwab et al (2012).



coronal or sagittal balance (Roussouly and Nnadi, 2010; Silva and Lenke, 2010).

A detailed description of the role and type of surgery is beyond the scope of this article. Broadly speaking, the goals of surgery are:

1. Relief of pain through decompression of the neural elements
2. Restoration of sagittal and coronal balance (Birknes et al, 2008).

In order to successfully achieve these goals the surgeon typically needs to perform a decompression and instrumented fusion with or without osteotomies to correct rigid deformities. Such surgery can be performed using a posterior approach to the spine, an anterior approach to the spine, a lateral approach to the spine, or a combination of approaches.

The benefits of surgery are evident in numerous studies demonstrating that patients treated operatively have significantly improved total pain, leg pain, self image and function compared to those managed non-operatively (Schwab et al, 2012; Smith et al, 2016).

That being said, adult deformity is high-risk surgery with the frequency of complications approaching 40%, including a 2.8% risk of mortality in those aged 60–70 years and 3.7% in those aged 70–80 years (Harding, 2014). Furthermore, the relief of symptoms may be below the patient's expectations. Consequently, the operating surgeon must discuss with the patient both the potential benefits and significant potential complications before scheduling surgery (Lenke et al, 2016).

Conclusions

Adult spinal deformity remains a challenging condition occurring in a heterogeneous patient population. The aging population means that this condition will increase in prevalence posing a medical and socioeconomic challenge.

Assessment of this patient group requires comprehensive three-dimensional clinical and radiological evaluation. In particular, understanding sagittal balance and the potential compensatory changes is critical in assessing and treating patients with adult spinal deformity. While most patients do not require surgical intervention, corrective surgery in appropriate patients has consistently been shown to improve patient outcomes (Schwab et al, 2007; Good et al, 2011). **BJHM**

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Conflict of interest: none.

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KEY POINTS

- Adult spinal deformity is an interesting and complex challenge.
- Adult spinal deformity can be divided into four categories: pre-existing childhood deformity, 'de novo', iatrogenic and secondary to systemic disease processes.
- Clinical assessment should be logical, comprehensive and well documented.
- Full length (36-inch) standing posterior-anterior and lateral radiographs represent the mainstay of radiological assessment.
- An appreciation of sagittal balance with pelvic parameters is important in understanding the effect and compensatory mechanism of observed deformities.
- Further imaging modalities such as magnetic resonance imaging, computed tomography and bone scans are used to answer specific clinical questions (e.g. neurological compromise, neoplasia and infection).
- Non-surgical intervention is the first line of treatment in most patients.
- Surgical intervention, despite being high-risk surgery, improves outcomes in the right group of patients.