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SPINE

# Adolescent idiopathic scoliosis in adulthood

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- Adolescent idiopathic scoliosis (AIS) is an abnormal coronal curvature of the spine that most commonly presents in adolescence.
- While it may be asymptomatic, AIS can cause pain, cosmetic deformity, and physical and psychological disability with curve progression.
- As adolescents with AIS enter adulthood, condition outcomes vary with some experiencing curve stabilization and others noting further curve progression, chronic pain, osteoporosis/fractures, declines in pulmonary and functional capacity, among others.
- Regular monitoring and individualized management by healthcare professionals are crucial to address the diverse challenges and provide appropriate support for a fulfilling adult life with AIS.
- This review examines the prevalence, risk factors, presenting symptoms, diagnosis, management, and complications of AIS in the adult population, informing targeted interventions by clinicians caring for adult patients with AIS.

Keywords: adolescent idiopathic scoliosis; adults; progression; quality of life; management

## Introduction

Adolescent idiopathic scoliosis (AIS) is the abnormal coronal curvature of the spine (Cobb angle ≥10°) that affects 0.5–5.2% of children ages 10–18 years (1, 2, 3, 4, 5). It is disproportionately seen in females, with a female-to-male prevalence ratio ranging from 1.5:1 to 3:1. While *de novo* scoliosis has a mean age of onset of 70.5 years, AIS often begins in late childhood or adolescence. Although the cause of AIS is unknown, a multitude of genetic and environmental factors are thought to play a role (6, 7, 8, 9, 10, 11, 12). As mild disease can be asymptomatic, diagnosis often requires early and frequent school screenings followed by radiographic confirmation (1). Management is subsequently dependent on the extent of the curvature, with simple observation and bracing for mild cases and surgical management for severe cases (13, 14).

Despite optimal management, AIS can continue into adulthood and result in chronic pain, disability, and cosmetic deformity (3, 4, 15, 16). Failure to diagnose AIS at its earlier stages or to recognize AIS as a debilitating lifelong condition can occur among clinicians and even delay treatment (17). This review aims to summarize data regarding AIS in adulthood, including prevalence, risk factors, presentation, diagnosis, management, and complications, such that clinicians can better understand and treat patients with this condition.

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# Epidemiology

## Prevalence

Scoliosis affects roughly 8% of adults over the age of 25 years and its prevalence rises to 68% in those over 60 years with the development of degenerative changes in the spine (5, 18). While it is known that AIS affects 0.5–5.2% of children ages 10–18 years, it is not known what proportion of these patients continue to have symptomatic AIS in adulthood (2, 3, 4, 5). The natural history of AIS is curve progression, mainly in curves that reach a cobb angle >40° at the end of growth; thus, an adolescent with AIS will eventually become an adult with AIS.

## Risk factors

Female sex is a well-known risk factor of AIS regardless of age (4, 16). Family history of AIS has also been associated in several twin/single-family studies and is likely a result of a complex interplay of multiple genes, including in the rs6570507 locus within GPR126 and in genes associated with the calmodulin pathway (11, 19, 20, 21). Radiographic features, in particular greater Cobb angle, cranially located apical vertebrae, and tilting of the L3 vertebrae, can also give insight into the development and progression of AIS (15, 22). Others including asymmetry of the body, muscular imbalances or weaknesses, and abnormal puberty have also been associated, though these factors are likely not causative but rather manifestations of associated genetic and soft tissue-related conditions (12).

# Presentation

In adolescence, AIS often presents with progressive deformity manifesting as asymmetric shoulder or hip height, body tilt, or unusual body prominence (1). Back pain is also commonly seen (3, 16). In adults, these symptoms may persist and progressively worsen, with correlation between AIS-associated back pain and need for surgery in adulthood (16). Chronically untreated patients may further develop respiratory and cardiac abnormalities due to their growing curvature affecting the contour of the thoracic cavity, thereby reducing its diameter and thus vital capacity (3, 23).

# Diagnosis

Diagnosis of AIS involves a thorough patient history, including personal growth and family history, followed by physical assessment for upright posture, unequal leg length, shoulder height discrepancies, truncal shift, and pelvic tilt. Early and routine screening has shown many benefits in preventing the severe physical and psychological sequelae of AIS in adults (1, 4, 15, 23). However, the evidence for the benefit of routine scoliosis screening is debated, with the U.S. Preventive Services Task Force and American Academy of Family Physicians (USPSTF) recommending against routine scoliosis screening in asymptomatic adolescents and the Scoliosis Research Society (SRS), American Academy of Orthopaedic Surgeons (AAOS), American Academy of Pediatrics (AAP), and Pediatric Orthopaedic Society of North America (POSNA) recommending for routine screening in all adolescents (1). Despite this debate, routine screenings with the Adams' forward bend test and scoliometers continue to be performed at regular wellness visits, with delays in diagnosis often stemming from a paucity of medical knowledge or a lack of awareness regarding the condition as opposed to a failure of screening (17).

## Physical exam

The Adams' forward bend test, which involves the patient bending forward at the waist with the knees straight and the examiner assessing for ribcage asymmetry and spinal deformity, is perhaps the most widely used screening test for scoliosis (Fig. 1) (1, 24). Scoliometers can also provide an additional quantitative assessment of truncal rotation, with >5–7° considered abnormal, but are generally considered to be less sensitive (Fig. 1) (1, 25, 26). Right thoracic curvature is most commonly observed; left thoracic curvature is atypical and can be associated with cysts or syrinx, warranting further workup with MRI spine screen (27).

## Imaging

Full-length 36-inch, or EOS imaging, can be used to visualize the spinal curvature in patients with suspected AIS (13, 28). Images are taken from posteroanterior (PA) and lateral views to assess for coronal and sagittal


**Figure 1**

Lateral view of the Adams' forward bend test (right) and use of a scoliometer during the test (left).

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plane abnormalities, respectively. The coronal films are especially useful for the measurement of Cobb angle. This indirect angle is a measure of scoliosis curvature calculated by identifying the superior and inferior endplates of the two vertebrae with the greatest tilt, drawing lines in parallel with the endplates, and measuring the angle at the intersection (29). Scoliosis can, then, be quantified and categorized as mild (10°–20°), moderate (21°–40°), and severe (>40°) (Table 1). The lateral films can provide further information about the associated changes in key sagittal parameters, including sagittal vertical axis, lumbar lordosis, pelvic incidence, pelvic tilt, and sacral slope.

In addition to upright imaging, fulcrum bending films and traction radiographs may be performed to determine the flexibility of curvature. Magnetic resonance imaging (MRI) may also be necessary for patients with neuromuscular symptoms, left thoracic curvature, or other atypical abnormalities to rule out malignancy, developmental abnormalities (e.g. syringomyelia), and structural issues (30, 31, 32, 33).

## Classification

Several classification systems have been devised to guide management of adult spinal deformity. The Aebi classification initially characterized spinal deformity by etiology, including primary degenerative (type I), progressive idiopathic (type II), and secondary (type III) scoliosis (34). The Scoliosis Research Society (SRS)–Schwab classification was later developed and incorporated coronal curve type and sagittal parameters, including pelvic incidence–lumbar lordosis mismatch, sagittal vertical axis, and pelvic tilt (35). In parallel, the Roussouly classification was refined and identified 'current' and 'theoretical' sagittal profiles based on pelvic incidence (36). Now, concurrent consideration of both the SRS-Schwab and the Roussouly classification system is made to define the severity of deformity and optimal realignment goals (37).

# Management of AIS in adults

Management of AIS is primarily dependent on the risk of progression. Once skeletal maturity is reached, the likelihood of progression of AIS is lower (38). Non-operative interventions, such as physical therapy and bracing, generally slow the progression of the spinal curve during adulthood. Operative interventions, such as spinal instrumentation and fusion, on the other hand, attempt to restore spinal curvature and improve coronal and sagittal spinopelvic alignment. Both, ultimately, hope to improve presenting symptoms and long-term outcomes.

## Non-operative techniques

### Exercise and physical therapy

Physiotherapy scoliosis-specific exercises (PSSEs) are considered as the first step in the management of mild scoliosis (4, 34, 39, 40). The Schroth method, the Scientific Exercise Approach to Scoliosis (SEAS), the Dobosiewicz technique, and the side-shift program, in particular, are the most frequently prescribed types of PSSE (41, 42, 43, 44, 45, 46). These techniques generally focus on enhancing posture control, muscle endurance, spinal stability, and overall balance.

### Bracing

Few studies have addressed initiating bracing in adult cases of AIS. Bracing is not common among adults due to barriers precluding its effective implementation including limited mobility, discomfort in high temperatures, and cosmetic displeasure (47). Modest evidence, however, indicates that bracing can slow down curve progression, reduce pain, and improve disability scores when worn for just 6 h daily (48, 49, 50).

## Indications for operative management

### Chronic back pain

Chronic back pain due to early AIS can develop or persist in adulthood and is generally more severe than that observed in the normal population (51, 52). A study by Ersen *et al.* has further shown an association with weight using data from the SRS-22, a questionnaire specifically designed to assess health-related quality of life in patients with AIS, noting that increased BMI is associated with chronic low back pain in both normal and scoliotic individuals (53). This can result in restrictions in daily activities, such as difficulties in walking, exercising, and socializing. Surgery tends to be more painful for adult patients compared to

**Table 1** Severity and treatment recommendations for AIS based on Cobb angle.

| Cobb angle magnitude | Severity and treatment |
|---|---|
| 0°–10° | Normal curvature; no treatment necessary |
| 10°–25° | Mild scoliosis; follow progression of curvature, re-evaluate after set period |
| 25°–40° | Moderate scoliosis; bracing |
| 40° and over | Severe scoliosis; surgical treatment may be necessary |

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adolescents, but long-term outcomes show a significant reduction in pain regardless (54).

### Poor physical function

Although AIS patients score similar to their peers in health-related quality of life (HRQoL) measures in mild disease, they may note a significant decline in HRQoL and physical functioning measures in adulthood in more severe disease (55). In one longitudinal study, Danielsson *et al.* found that patients with mild AIS had comparable HRQoL as the general population 20 years after treatment with bracing or surgery (3). The degree of curvature after treatment, total treatment time, or age at the completion of treatment played no apparent role. On the other hand, patients with severe AIS, particularly with curves greater than 50°, note significant limitations in activities of daily living and physical functioning. Surgical treatment in this population can prevent and alleviate these conditions, with treated adults showing significant improvements in their physical functioning (54). Such restoration in functional mobility can also improve performance at work, reducing absenteeism and increasing productivity by 18.1% post-surgical intervention (56).

### Low self-image

AIS patients have also been shown to consistently suffer from decreased self-esteem and poor psychological health due to negative body image, regardless of disease severity (57, 58, 59, 60). In particular, longer bracing durations, older age at initial bracing, and higher Cobb angles have been associated with greater depression symptoms and more deformed physical appearance, particularly in older patients who may be more conscious of their body image (61, 62). This decline in self-image is typically worse in surgically treated patients, likely due to spinal fusion-related stiffness and scarring, and awareness of implants and surgical incisions (63, 64).

### Osteopenia/osteoporosis

Continued AIS in adulthood is associated with reduced bone mineral density (BMD), leading to osteopenia and osteoporosis (65). Studies have shown that 20–38% of adults with a history of AIS develop osteoporosis later in life, often at an earlier age than the general pediatric and adolescent population (66, 67). Moreover, even with early treatment of AIS, these patients may still lose BMD and develop significant intervertebral disc degeneration in adulthood than matched controls (68, 69). The loss of bone density could be due to abnormal mechanical loading in scoliotic patients, resulting in localized areas of increased or decreased resorption. Serial imaging and DEXA screening is, thus, warranted in patients with AIS (9).

### Respiratory decline

Eventually, adults with untreated or severe (Cobb angle ≥40º) AIS may develop respiratory function decline, including reduced vital capacity and frequent shortness of breath (70). This may further exacerbate chronic back pain, emotional distress, and reduced quality of life. However, such severe cardiopulmonary compromise is rare and the associated impact on morbidity and mortality may, in fact, be similar between patients with and without AIS (70). Further longitudinal studies would need to be conducted to confirm this relationship.

## Pregnancy-related implications

Although concerns have been raised about the impact of AIS on pregnancy and vice versa, studies have shown that spinal curves do not affect fetal growth or significantly worsen during pregnancy (71, 72). Likewise, complication rates following surgical intervention for severe curvature during pregnancy and/or delivery do not significantly differ between patients with and without AIS (73). However, the additional weight of the fetus does place eccentric mechanical load on the scoliotic spine, possibly exacerbating chronic pain in AIS. This may subsequently explain the higher rates of C-section in women with AIS than those without AIS (74).

## Operative techniques

Surgical intervention in adults with AIS is primarily indicated for focal painful deformities, compressive neurological conditions, and global spinal imbalance. The mainstay of surgical treatment is spinal instrumentation and fusion. During spinal fusion, anchors connected to longitudinal rods spanning the desired length of fusion are fixed to the vertebrae with screws inserted into the pedicles. Bone grafting can then be used to promote fusion between the individual vertebrae (75). Most spinal fusions are performed using posterior approach. However, in some cases, a combined approach can be used (i.e. minimally invasive lateral (XLIF (extreme lateral interbody fusion)) or retroperitoneal anterior (ALIF (anterior lumbar interbody fusion) or OLIF (oblique lateral interbody fusion))) (76, 77).

Figure 2 demonstrates pre-/post-operative radiographs for a 43-year-old female with untreated AIS who underwent T3–L2 fusion. Figure 3 similarly illustrates pre-/post-operative radiographs for a 64-year-old female with progressive AIS in both the coronal and sagittal plane who underwent an upper thoracic to pelvis fusion after failing conservative management. Anterior spinal fusion (ASF) is often saved for the correction of lumbar hypolordosis and thoracic hypokyphosis, as it allows for a greater degree of sagittal curve correction and improved postoperative mobility of the spine (78). Combined anterior and posterior spinal fusion may,

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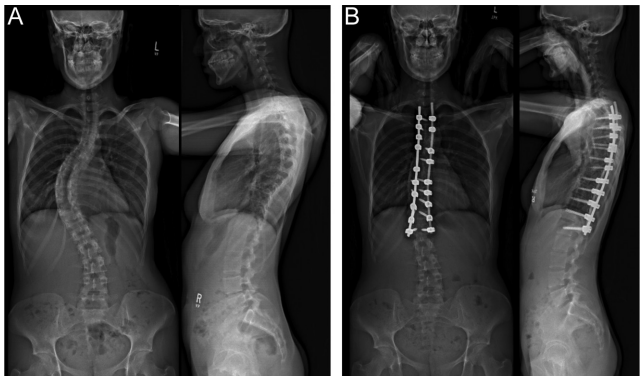


**Figure 2**

A 43-year-old patient who underwent a selected T3–L2 fusion for untreated AIS presenting with back pain (A: pre-operation and B: 2 months post operation).

ultimately, be necessary in cases of large curvature as it allows for a greater degree of curve correction, decreased stress on the construct, and improved overall fusion.

# Complications

## Acute complications

Coe *at al.* performed an analysis of the surgeon-reported SRS morbidity and mortality database, which included 6334 patients who underwent spinal fusion surgeries for AIS, and found an overall complication rate of 5.7%, with higher rate for combined anterior/posterior procedures (10.2%) compared to posterior (5.1%) and anterior (5.2%) procedures alone (79). Early or late infection, implant failure (pseudarthrosis), and recurrence have all been estimated to be approximately 1–2%; neurological complications occur even more infrequently, at less than 1% (80). Furthermore, when comparing young adults to adolescents after AIS surgery, Lavelle *et al.* showed that young adults had more levels fused, more intra-operative blood loss, and a lower percentage of correction at 21 months follow-up (80).

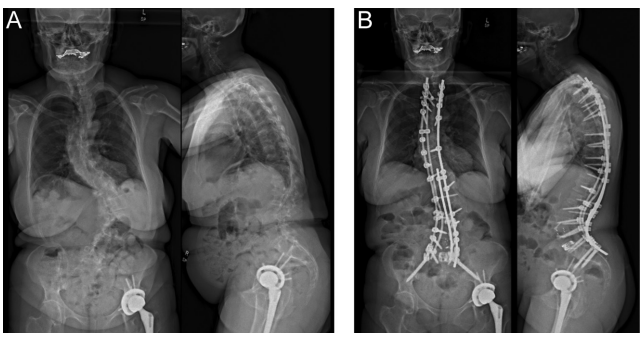


**Figure 3**

A 64-year-old patient who underwent a T2–pelvis spinal fusion for untreated scoliotic deformity presenting with lower back pain and worsening of posture (A: pre-operation and B: post operation).

## Chronic complications

Adjacent segment disease, proximal junctional kyphosis, and flatback syndrome can occur as a consequence of a multi-level fusion (81, 82, 83, 84, 85, 86). Although patients with these conditions may not always present with any specific complaints, they still need to be examined by deformity specialists because they may develop neurologic deficits due to compression or injury to the spinal cord or nerve roots (86, 87, 88, 89, 90). Presence of pain, on the other hand, may be an indication of hardware failure and potential neurologic injury. In particular, postoperative weakness, gait abnormalities, and pain at the top or bottom of the fusion may be suggestive of a neurologic injury and warrant emergent imaging and evaluation by a deformity specialist.

# Conclusion

AIS in adulthood is a common but underrecognized disorder with a multifactorial etiology. Early detection of AIS is crucial for the development of an effective and patient-specific management plan. Both non-surgical and surgical interventions are available, with treatment depending on various factors including severity of spinal curvature and risk of curve progression. While non-surgical approaches such as observation and bracing are generally considered the first line of treatment, surgery and orthopedic referral is recommended for severe cases, especially among those with rapid curve progression, pain, disability, or associated neurological compression syndromes. Adult treatment of AIS requires critical evaluation of clinical data as well as consideration of individual alignment parameters and should be reserved for spinal deformity specialists in lieu of the general spine surgeon.

**ICMJE Conflict of Interest Statement**
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