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Adult Degenerative Scoliosis: A Literature Review of Current Concepts and New Trends

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ABSTRACT

Background Data: Degenerative scoliosis in adults is a growing health problem due to the steady increase in lifespans globally. It is a benign health problem, but it develops slowly in nature.
Purpose: To review the available data about degenerative scoliosis in adults and the recent concepts and treatment options.
Study Design: A narrative literature review.
Patients and Methods: The author reviewed the English literature published through the last two decades for recent and relevant data about the pathogenesis, presentation, and management of adult degenerative scoliosis. A PubMed search was conducted using both phrase searching and combined searching using Boolean operators. The most relevant articles according to the study aim and spine surgeon's practice were extracted.
Results: Adult degenerative scoliosis is a triplanar deformity affecting coronal and sagittal parameters and axial spinal dimensions. The condition starts with age-related disc degeneration and progresses slowly over the years with worsening back pain and neurological deficits in advanced stages. Selected stable patients with early deformities can be managed nonsurgically through various pharmacological, physical, and interventional measures. However, most cases with degenerative scoliosis are best treated surgically via various open or minimally invasive procedures, reserving the conservative measures for nonsurgical candidates or as preoperative palliation.
Conclusion: Adult degenerative scoliosis is best managed by a multidisciplinary team of neurosurgeons and orthopedic surgeons in a patient-specific manner. Further studies are required for comparing and identifying the best surgical strategies in a patient-specific approach. (2021ESJ249)

Keywords: degenerative, scoliosis, deformity, adult, elderly, aging spine

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INTRODUCTION

Currently, global demography is witnessing a shift toward population aging due to recent advances in medical care, increased lifespan, and reduced birth rates.[42,73,142] These demographic shifts have been associated with a substantial increase in the burden and prevalence of musculoskeletal diseases, notably adult spinal deformities. Adult spinal deformities (ASD) have been reported to affect almost one-third of the population over the age of 50 years and more than two-thirds of those over 70 years.[1,106] These deformities have a considerably crippling effect on general health, resulting in disabilities that are comparable to those of several cancer types and exceeding those of hypertension and diabetes.[15] Additionally, ASD can cause psychological distress and comorbid mental disorders in 27–38% of affected individuals.[32,34]

ASD refer to a spectrum, including adult scoliosis, iatrogenic sagittal plane deformities (like flat-bak syndrome), degenerative hyperkyphosis, degenerative focal deformities, and posttraumatic deformities.[3,6,123,146] However, adult scoliosis is a blanket term that may refer to degenerative scoliosis (ADS) and degenerative progression of a preexisting adolescent idiopathic scoliosis (AIS) based on whether the deformity commenced before or after skeletal maturity, receptively.[132] Adult degenerative scoliosis is also known as de novo scoliosis, referring to a spinal deformity that develops after skeletal maturity in a previously healthy spine featuring a coronal plane curvature with a Cobb angle >10 degrees.[3] The global increase in the prevalence of ADS has witnessed an increase in patient demands for surgical corrections to alleviate pain and achieve both functional and cosmetic improvement.[94]

The aim of this narrative review was to summarize the current concept in the literature about adult degenerative scoliosis, highlighting its triplanar nature, pathophysiology, presentations, and available surgical options.

PATIENTS AND METHODS

English literature relevant to the topic was reviewed through the last two decades. The PubMed database was last searched by the author for studies related to the topic of adult degenerative scoliosis on July, 2021. The search process is composed of primary and secondary searches. The primary search is composed of both phrase searching and combined searches using Boolean operators. Phrase searching was done using the following phrases: "adult degenerative scoliosis", "degenerative spinal deformity" and "adult spinal deformity". Using advanced search, Boolean search box was used to search the following: [adult] AND [scoliosis], [adult] AND [deformity], [scoliosis] AND [elderly], [degenerative] AND [scoliosis] & [lumbar] AND [scoliosis]. Secondary research was done in a delayed fashion during scientific writing for further complementary studies. The author used Boolean search again such as [osteotomy] AND [deformity], [scoliosis] AND [stenosis], [sagittal] AND [deformity] & [aging] AND [spine]. The selection process of articles was subjective and based on the discretion of the researchers, landmark studies, and literature reviews that are relevant to the study aim from the author's point of view. Scarcity of randomized controlled trials was noticed, with plenty of cohort studies and systematic reviews based on retrospective cohorts.

RESULTS

Epidemiology:

Adult degenerative scoliosis starts after skeletal maturity and presents at a mean age of 70.5 years, being prevalent in about 6% of adults above the age of 50 years and rarely before 40 years.[48,132] Contrary to progressive AIS in adulthood, ADS affects males and females and, similarly, mostly involves the lumbar region, features a smaller Cobb angle (< 40 degrees), and advances at a faster rate (1.64 degrees/year vs. 0.82 degrees/year).[50,77] The prevalence of the curve in ADS is inversely proportional to its magnitude, where 10º, 10-20º, and > 20º curves are prevalent at 64, 44, and 24%, respectively.[118]

Pathogenesis:

The triggering event for ADS is believed to be the age-related disc degeneration process. With aging, the increased proteases activity and proteoglycans loss lead to disc dehydration,[134] with both micro- and macrostructural anatomical and biomechanical changes resulting in a reduction in the disc height and, ultimately, failure of the load-bearing and stabilizing role of the intervertebral disc.[4,118,147] These changes predispose to facet joint overload resulting in bone remodeling and joint instability.[127] When these degenerative changes take place in an asymmetrical fashion, a progressive imbalance occurs in axial loading causing asymmetrical bone remodeling with a subsequent decline in spinal ligaments and paraspinal muscles, leading to spinal instability and deformity.[7,13,33,62,78] In the presence of asymmetry in axial loading, the deformity progresses annually by 3º or more.[11] The progressive deformity in the coronal plane together with facets and ligaments hypertrophy result in stenosis in the central canal, lateral recesses, and foramina.[115]

In addition to the coronal plane deformity that characterizes ADS, a sagittal plane deformity usually exists to some extent. Sagittal malalignment is a recognized factor that directly correlates with axial back pain and the quality of life.[57,111] Patients with sagittal malalignment who fail to compensate due to age-related muscle weakness, stiffness, and reduced range of motion are considered to have a positive sagittal balance and were found to suffer from disabilities and worse health-related quality of life scores.[46] Sagittal balance was found to be primarily determined by the pelvic incidence (PI) and lumbar lordosis (LL). PI is a fixed morphological parameter of the pelvis and has a mean value of 55 ± 10 degrees.[135] Pelvic tilt (PT) is a parameter that quantifies pelvic rotation around the femoral heads that increases with retroversion and decreases with anteversion of the pelvis. Sacral slope (SS) is a related parameter that quantifies S1 endplate position. Geometrically, PI equals the sum of PT and SS. Ideally, PT should be < 50% of PI, while SS should be > 50% of PI.[74] For achieving spinal balance in the sagittal plane, LL as measured from L1-S1 should closely match the PI. [112] A frequently used parameter for measuring global sagittal balance is the sagittal vertical axis (SVA). It is the horizontal distance between the C7 plumb line and the superior posterior corner of S1. The SVA is considered positive if the C7 plumb line passes >2 cm anterior to the S1 corner and negative if it passes >2 cm behind it. Positive SVA >5 cm is abnormal and associated with pain and disability.[46]

Several factors are implicated in ADS development, including genetics, smoking, obesity, fatty degeneration of paravertebral muscles, senility-related balance and mobility disorders, and associated neurodegenerative diseases.[36,106,145] Although osteoporosis was previously assumed to be a contributing factor, current studies found osteoporosis to be equally prevalent among ADS patients and the general population, with no correlation between curve magnitude and the degree of osteopenia. On the contrary, bone mineral density on the concave side of the deformity and ipsilateral femur was revealed to be higher when compared with the contralateral side.[101]

Classification:

Numerous classification systems (54 different classifications) have been identified for ASD; the most used and cited was the revised Scoliosis Research Society-Schwab (SRS-Schwab) classification.[64] This classification system included a description of the coronal plane curves featured in ADS with the incorporation of sagittal parameters recognized to be important predictors of health-related quality of life and was revealed to be of excellent inter- and intrarater reliability (Figure 1).[112] This classification has been validated and worse sagittal modifiers were found to be associated with poorer quality of life and to be

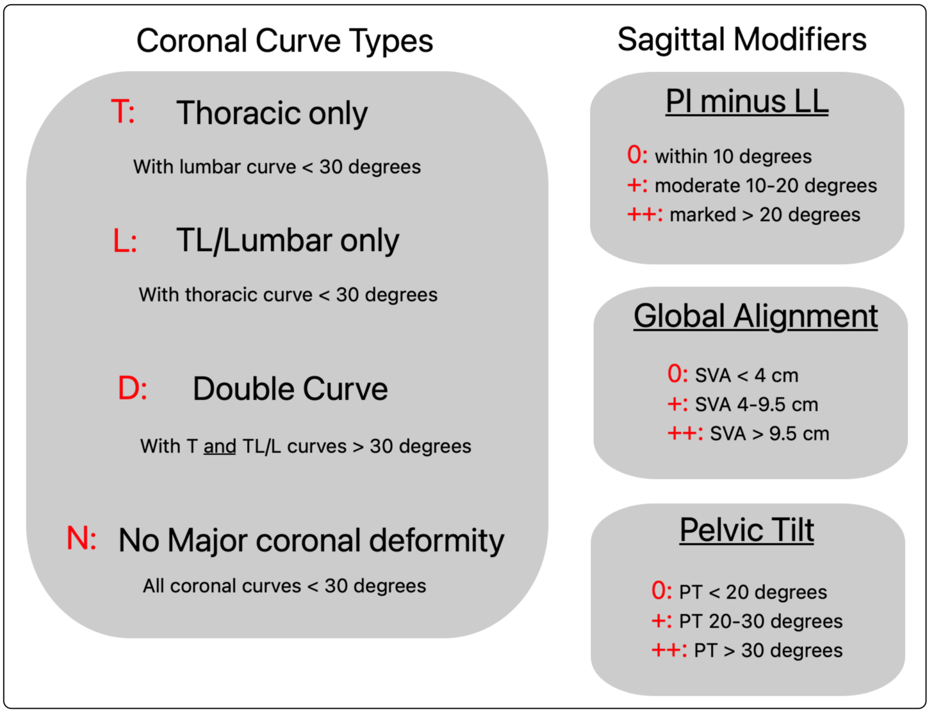

Figure 1. SRS-Schwab classification for adult spinal deformity. It includes four coronal curve types and four sagittal modifiers. T: thoracic; TL: thoracolumbar; L: lumbar; PI: pelvic incidence; LL: lumbar lordosis; SVA: sagittal vertical axis; PT: pelvic tilt (by Terran et al., 2013).[121]

indicated for surgeries with larger magnitudes. [130] One of the earliest and simplest classifications was the Simmons classification categorizing scoliosis into two types based on having no or minimal rotation (type I) or having rotational deformity with reduced LL (type II). [119] Type I deformities were treated using short, instrumented fusions with the traction of the concave side, while type II indicated long instrumentation with derotation techniques.[120] Some systems classified ADS based on the cause of the deformity, such as Aebi classification which described four types (types I, II, IIIa, and IIIb) with only type I representing true de novo scoliosis[3] (Table 1).

Other classifications aim to identify the most proper surgical intervention for ADS patients; the Faldini classification system is an example.[40,41] It classified ADS into type A (stable) and type B (unstable), with each type classified into four subtypes according to the main element contributing to the clinical picture of the patient (Table 2). Subsequently, Schwab developed a classification system based on the curve apex in the coronal plane with two modifiers: LL and intervertebral subluxation.[108,109] Later, it has come to light how sagittal parameters can influence function and predict the quality of life, so the revised SRS-Schwab classification was developed incorporating relevant spinopelvic parameters.[112]

Table 1. The Aebi classification for ADS.[2]

Curve type	Characteristics
Type I	"De novo'' scoliosis, due to an asymmetrically degenerated disc. Presence of spinal stenosis, which can be central, foraminal, or conjoined
Type II	Progression in adulthood of a previously stable idiopathic scoliosis (during childhood). Curves are combined with secondary degeneration and/or imbalance
Type IIIa	Curves due to diseases within the spine or from diseases located outside of the spine
Type IIIb	Deformities resulting from bone weakness in the contest of metabolic bone diseases, combined with an asymmetric segmental degeneration. Bone weakness may be responsible for fractures with consequent asymmetric configuration and kyphosis, scoliosis, or both together

Table 2. The Faldini classification system[38]

Curve type	Classification	Decompression	Fusion
A (stable)	**A1:** Facet hypertrophy with foraminal stenosis	-Hemilaminectomy plus unilateral foraminotomy -Laminectomy plus bilateral foraminotomy	-No fusion -Posterolateral fusion with/without instrumentation
	A2: Facet hypertrophy with central stenosis	-Hemilaminectomy -Hemilaminectomy plus unilateral foraminotomy -Laminectomy plus bilateral foraminotomy	-No fusion -No fusion -Posterolateral fusion with/without instrumentation
	A3: Intervertebral disc degeneration	-Hemilaminectomy plus unilateral foraminotomy -Hemilaminectomy plus unilateral foraminotomy plus discectomy and restoration of disc height	-Posterolateral fusion with/without instrumentation -Interbody fusion plus posterolateral fusion with/without instrumentation
	A4: Mixed	-Hemilaminectomy plus unilateral foraminotomy -Laminectomy plus bilateral foraminotomy	-No fusion -Posterolateral fusion with/without instrumentation OR Interbody fusion plus posterolateral fusion with/without instrumentation
B (unstable)	**B1:** Hypermobility due to facet joint degeneration	-No decompression -Hemilaminectomy plus unilateral foraminotomy -Laminectomy plus bilateral foraminotomy	Posterolateral fusion with/without instrumentation
	B2: Disc degeneration	-Unilateral foraminotomy -Bilateral foraminotomy	Posterolateral fusion with/without instrumentation OR Interbody fusion plus posterolateral fusion with/without instrumentation
	B3: Mixed	-Unilateral foraminotomy -Bilateral foraminotomy	Posterolateral fusion with/without instrumentation
	B4: Unstable with sagittal imbalance	-Unilateral foraminotomy -Bilateral foraminotomy	Interbody fusion plus posterolateral fusion with/without instrumentation

Despite the numerous classifications available, no single classification included all dimensions that are related to the clinical presentation of patients, support decision-making, and play a part in predicting treatment outcomes. It appears that no evidence exists that available classification systems can affect the outcome. [64]

Health Impact and Disability:

It is globally accepted now that ADS is one of the most disabling and psychologically distressing health issues. In a study comparing the Standard Form Version 2 (SF-36) scores for patients with symptomatic adult spinal deformity (sASD) with US normative and chronic disease scores, the authors found that the physical component summary (PCS) for sASD patients worsened in the presence of scoliosis and severe positive sagittal balance (SVA >10 cm). Moreover, patients with combined scoliosis and SVA >10 cm demonstrated significantly worse PCS scores than patients with limited use of arms and legs. [15] In another study carried out by Schwab and colleagues,[107] the authors studied the burden of adult scoliosis using SF-36 questionnaire and compared values to patients with different medical comorbidities and to benchmark US general population values. Scoliosis patients scored worse in all 8 SF-36 domains than the general population. Acaroğlu and colleagues studied and demonstrated the heterogeneity of patients with adult spinal deformity and reported the need to stratify patients as early and late presentation and/or by diagnosis. They reported that patients with degenerative curves tend to be older, have worse health-related quality of life parameters, have curves at lower locations, and be more unstable in the coronal plane. These studies reflect the importance of using health-related quality of life parameters and questionnaires to understand the extent of ADS impact on patients' daily life beyond the conventional radiographic assessment previously carried out by spine surgeons.

However, the impact of ADS does not stop at the stage of physical disability and chronic pain only. The psychological and mental burden in these patients was well recognized and can affect outcomes after surgery. A study comparing mental health in patients with scoliosis to the general US population found a significant difference in mental health scores (10 to 30 points in SF-36 mental component summary scales) between both groups. [107] Diebo and colleagues[123] found that 37.5% of patients undergoing four or more levels of spinal fusion had one or more psychological comorbidity, with depression, sleep disorder, and anxiety being the most common. These patients showed higher rates of complications at two years compared to controls who underwent the same operation types.

Clinical Assessment:

Patients with ADS present with various symptoms starting with axial back pain, radicular pain, claudication pain, and eventually progressive or even acute neurological deficits. Axial back pain is considered the most common presenting symptom occurring in up to 90% of cases. [14, 94] The back pain criteria are determined by the triggering element of pain. The pain generated by the coronal deformity itself (i.e., in the absence of significant sagittal deformity) is poorly localized, experienced over the convexity of the curve, is primarily due to paraspinal muscle fatigue, and, as a result, responds well to physical rest. When there is a significant positive sagittal balance, the low back pain tends to localize over the central lower lumbar region, sacrum, and iliac crests with well-identified trigger points of pain. [59] Presence of lumbar instability adds a mechanical nature to the criteria of axial back pain, like painful arc during flexion and return, Gower sign, instability catch, and/or reverse lumbopelvic rhythm. [44] Moreover, associated spinal canal stenosis is frequently seen in patients with ADS. Pain induced by spinal stenosis in ADS is not improved by the same maneuvers seen in spinal stenosis without scoliosis. An interesting distinction between both types of pain was made by Silva and Lenke, where pain resulting from stenosis on top of ADS was relieved on sitting with patient's trunk supported by their arms, not by just attaining a forward posture. [118] This distinction is crucial as treatment and prognosis of degenerative stenosis differ from those of ADS.

Besides axial back pain, presentation with leg pain is also common. Unilateral leg pain is usually caused by radiculopathy resulting from foraminal or lateral recess stenosis by a single or multiple disc herniation, facet joint degeneration, and/or osteophyte formation. However, in the case of bilateral leg pain, whether symmetrical or not, the underlying pathology should be carefully investigated. It has been long considered that bilateral leg pain in ADS occurs in the context of spinal stenosis.[11] However, Foley and colleagues[43] emphasized that bilateral leg pain should not be misrecognized as being neurogenic claudication from existing central canal stenosis, but the consideration of bilateral radiculopathy as a possible etiology should always be in mind. On the concave side, radiculopathy is usually the result of foraminal or lateral recess stenosis, while on the convex side, it is better described as a result of dynamic traction on lumbar roots causing pain even in the absence of radiological evidence of compression.[3, 9, 94] Ploumis and colleagues found radicular symptoms more frequently affecting L4 (34.8%) and L5 (28.3%) roots. They reported that 71.7% of radicular symptoms originated from the concave side of the curve, but 28.7% from the convex side.[93]

The natural history of untreated ADS reflects a progressive clinical course due to progressive deformity with worsening axial and radicular pain and eventually neurological deficits in late stages.[11] Several predictors of curve progression have been identified, including grade 3 apical rotation, Cobb angle >30º, laterolisthesis ≥6 mm, and the prominence of L5 in relation to the intercrest line.[98] During the clinical evaluation of patients with ADS, a differential diagnosis and associated comorbidities should be considered. Pathologies of hip and sacroiliac joints, abdominal aortic aneurysms, pelvic malignancies, pancreatic carcinomas, and cervical myelopathy may be underlying pathologies mimicking the clinical presentation of ADS.[94] Associated comorbidities, such as ischemic heart disease, diabetes mellitus, previous stroke, heavy tobacco consumption, and psychiatric disorders, are paramount aspects that should be taken into consideration when planning for a treatment strategy.

Radiological Assessment:

A good starting point in the radiological assessment of ADS is the orthostatic whole spine posteroanterior and lateral radiographs. When these radiographs are performed perfectly, they become very useful in assessing coronal and sagittal balance. These radiographs are generally performed, while the patient is attaining a comfortable upright posture with bare feet, arms crossed upon their chest, and looking directly straight forward. The tube is better centered at the xiphoid process, at about 2.5 meters without magnification. Ideal radiographs should extend from the occiput proximally to the middle of the femurs distally to enable the examiner to evaluate global coronal and sagittal balance, measure various pelvic parameters, and assess hip joint contractures. Sagittal balance has been proven to be of paramount importance in the assessment of spinal deformities and the prediction of quality of life.[105] Further evaluation of hip and knee joints via local radiographs can reveal local joint pathologies that can affect patient's compensatory corrective flexions. Additionally, flexion/extension views and lateral bending radiographs are routinely done to assess curve flexibility and stability of the spine. In coronal views, the surgeon should assess pelvic obliquity to rule out any potential discrepancy in the length of lower limbs. Moreover, Cobb's angles for all curves as measured between the endplates of the most inclined upper-end and lower-end vertebrae and coronal balance as measured by the distance between the C7 plumb line and central sacral vertical line (CSVL) should be estimated from coronal views.[145] In addition, proximal and distal stable vertebrae of the major curve, L3 and L4 endplate obliquity maximal lateral displacement, and Nash–Moe grade of the apical vertebra are useful coronal parameters. In sagittal views, thoracic kyphosis (T5-T12), thoracolumbar kyphosis (T10-L2), and LL (L1-S1) are measured. The global sagittal balance is evaluated by calculating the SVA between the C7 plumb line and the posterior superior corner of the S1 vertebra (Figure 2).

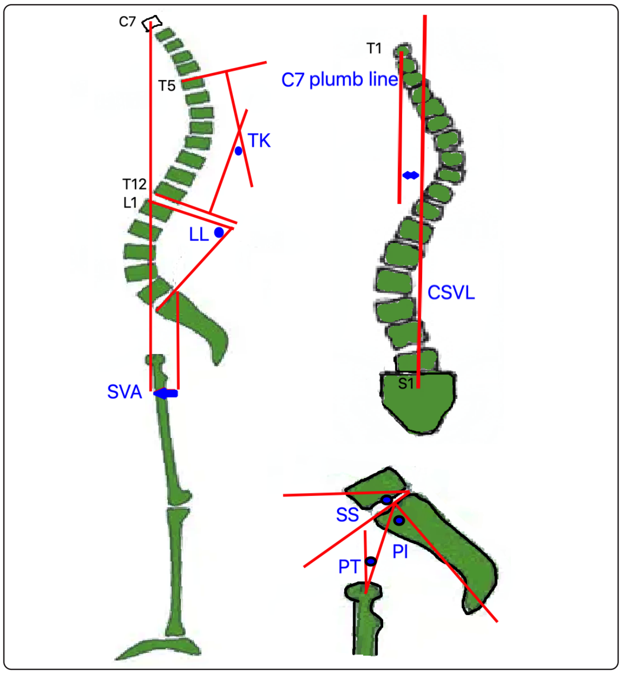

Figure 2. Artistic drawing (by the author) demonstrating various coronal and sagittal spinopelvic parameters. CSVL: central sacral vertical line; TK: thoracic kyphosis; LL: lumbar lordosis; SVA: sagittal vertical axis; PI: pelvic incidence; PT: pelvic tilt; SS: sacral slope.

A mismatch between pelvic incidence and lumbar lordosis (PI-LL mismatch) can be calculated in whole spine lateral views helping in curve classification and giving an impression about the magnitude of correction required during surgical planning to achieve sagittal balance. Moreover, some sagittal parameters can be used to predict disability (Oswestry Disability Index >40) and are considered sagittal modifiers in SRS-Schwab classification, such as PT of 22º, SVA of 46 mm, and PI-LL of 11º.[112] Predictors of curve progression can be derived from both coronal and sagittal films during the initial assessment of patients and decision-making, as previously mentioned.[98]

Despite being a controversial issue, some authors suggest the usefulness of discography to identify discs contributing to pain generation and thereby the need to incorporate them into planned fusion.[10] MR imaging in ADS can add information about disc degenerative status and neural element compression; however, its interpretation may be difficult due to the complex 3D pathology of the curve.[94] In the presence of an absolute contraindication to MRI, a CT scan of the spine with/without myelography may represent an alternative tool to assess both neural and bony anatomy.[11] A new advance in ADS imaging is using the EOS™ X-ray machine, which utilizes ultra-low radiation doses to simultaneously capture biplanar radiography to construct a 3D image of the whole skeletal system in a load-bearing upright position. The EOS system performs all measures obtained from 2D radiographs, with the additional advantage of being easily understood by the patient.[55]

Management Options

(1) Nonsurgical Management:

Pharmacological Treatment:

Nonsurgical management is usually the first step in managing ADS. Modification of physical activity, patient education, and use of nonsteroidal anti-inflammatory drugs and nonnarcotic analgesics are tried initially with all patients. The addition of a short course of steroids, if not otherwise contraindicated, can help acute severe pain, while the use of gabapentin and tricyclic antidepressants are prescribed for chronic persistent pain. These medications are rarely quite effective and generally poorly tolerated in old age.[13,59]

Bracing and Casting:

Regarding bracing and casting to stabilize the spine and restore sagittal alignment, previous studies reported short-term improvement in ambulation and pain with poor patient compliance.[137,138] In a systematic literature review, weak evidence (Level IV) was found to support bracing or casting in adult scoliosis.[39] Later, in a study by Weiss and colleagues,[140] the authors treated 67 patients with scoliosis or hyperkyphosis using sagittal realignment brace (physio-logic brace™) and reported promising mid-term improvements in pain intensity even in those who stopped using the brace after the initial six months. The authors recommended the use of a sagittal realignment brace before considering surgical options. In a pilot study testing the role of bracing in adults with chronic back pain and scoliosis, the authors reported that Peak Scoliosis Brace achieved some pain improvement at one month with no significant change in the quality of life.[148] Despite these results and results from other case reports, high-quality evidence to support bracing in adults with spinal scoliosis or other deformities is still lacking in the literature.[139]

Physical and Interventional Therapy:

Achievement of significant pain relief and curve improvement were reported in ADS treated with heat, lumbar traction, and traction combined with pressure applied to the curve apex.[12] However, several methodological shortcomings such as lack of description of the traction protocol and independence of radiograph reviewers made conclusions difficult to confirm. Manual therapy was proposed to release myofascia and help balance via neurophysiological mechanisms.[17] Although it was recommended by Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) guidelines in combination with stabilization exercises for adolescent scoliosis,[83] no high-quality evidence exists to support its use in ADS.[89] The addition of exercise to myofascial release has demonstrated beneficial effects on function, posture, and subjective well-being.[31] However, spinal instability and curve progression are concerns associated with excessive spinal manipulation.[80]

Exercise was reported to improve curves in some adults by improving the postural collapse component of the curve, thus reducing asymmetrical loading, asymmetrical degeneration, and curve progression.[82] Other physical modalities like thermotherapy and transcutaneous electrical nerve stimulation can be used in some patients; however, the level of evidence supporting its use is indeterminate.[36] On the other hand, a systematic review demonstrated that steroid injections had Level III evidence in managing adult scoliosis.[39] Selective root injection, epidural injection, trigger point injection, and facet blocks can also be performed. Sometimes, multiple level injections are required as pain generators may be multisegmental.[3] Diagnostic injections can be performed preoperatively to help in planning the extent of decompression.[145] However, the rate of initial pain relief after selective root injection does not correlate with the MRI-estimated degree of stenosis.[93]

Recently, "prehabilitation" became a commonly used term referring to preoperative rehabilitation and has been studied widely. One-third of Swedish and Dutch surgeons and 1 of 30 British surgeons refer their patients to prehabilitation.[102] Six weeks of prehabilitation was reported to be associated with a shorter hospital stay, lower costs, and earlier achievement of postoperative milestones.[84,85] However, a randomized controlled trial comparing patients who had prehabilitation to a waiting list advised to keep active failed to find any significant difference postoperatively, despite the better quality of life preoperatively, and suggested to select patients who might benefit from prehabilitation.[71] Similarly, no evidence-based recommendations exist for return to work or physical activity following lumbar fusion in ADS. Survey studies demonstrated that safety and activity recommendations given by surgeons after lumbar fusion of adult deformities greatly vary.[102, 133] Although supervised pre- and postoperative rehabilitation may be associated with reduced complications and accelerated recovery, all available studies and recommendations are of low quality regarding the role of rehabilitation in ASD.[89]

(2) Surgical Management:

Adult degenerative scoliosis is a pathology that is best managed surgically, with nonsurgical measures reserved as a palliative treatment for those who are not fit for surgery or as a part of preoperative preparation and pain control. Patients treated surgically were found to have a statistically significant improvement in performance and quality of life with less chance of clinical deterioration when compared to those treated by nonsurgical measures.[114] Surgery is generally indicated in ADS with any or a combination of the following: a) disabling back pain not improving with nonsurgical measures; b) new-onset or progressive neurological deficits; c) curve progression resulting in coronal and/or sagittal imbalance causing easy fatigue and worsened quality of life; d) a cosmetic purpose when requested by a fit surgical candidate.[18, 51, 94] Radiographically, the main parameters that predict curve progression and, thus, indicate surgical intervention are as follows: a) curves with Cobb's angle of 30º or more; b) laterolisthesis of 6 mm or more; c) grade 3 apical rotation; and d) prominence of L5 in relation to the intercrestal line.[98]

The main goals of corrective scoliosis surgery are as follows: a) restoration of sagittal balance; b) adequate neural decompression; c) avoidance of complications; and d) improving the quality of life.[86] In order to achieve these goals, long segment fusion has been considered the procedure of choice and was reported to provide more chance of satisfactory outcomes.[27, 98] However, some authors adopted performing minimal surgical interventions to manage the presenting symptoms in degenerative scoliosis.[118] Minimally invasive surgery in ADS is getting more popular, achieving comparable long-term outcomes with lower morbidity than traditional surgical techniques.[8,56] In a prospective analysis of 872 patients undergoing lumbar and lumbosacral fusions, the authors reported a 23% complication rate with three factors exhibiting significant association with complications rates: a) the extent of fusion zone; b) several comorbidities; c) excess weight.[49] In another retrospective analysis of adult spinal deformity surgery, the complication rate was 37%, with major complications representing 20%. The authors found age to be a significant factor predicting complications, where patients older than 69 years had more complication rates.[30] For the several risk factors frequently existing in patients presenting with ADS, surgeons should carefully select surgical candidates and construct the surgical plan in order to achieve the main goals of corrective surgery.

Several surgical approaches were described in the literature for managing patients with ADS. Silva and Lenke[118] categorized these approaches into six levels of operative treatment: I, decompression alone; II, decompression and limited instrumented posterior spinal fusion; III, decompression and lumbar curve instrumented fusion; IV, decompression with anterior and posterior spinal instrumented fusion; V, thoracic instrumentation and fusion extension; VI, inclusion of osteotomies for specific deformities. They presented a matrix to help surgeons to sort the patient's clinical and radiographic parameters into these levels of treatment (Table 3).

Posterior Decompression Alone:

Various decompressive procedures can be performed for neural release in patients with ADS, such as laminotomy, laminectomy, hemilaminectomy, foraminotomy, and/or extraforaminal decompression. When used wisely and skillfully in indicated cases respecting important surrounding osseous and soft tissue structures, these procedures can achieve adequate neural release with minimal or no risk on curve progression. Decompression alone is indicated in the presence of central canal, lateral recess, and/or foraminal stenosis, in the context of mild deformity curves (i.e., Cobb's angle < 30º, laterolisthesis < 2mm, good sagittal balance, and anterior osteophytes), in the absence of significant axial pain and with lack of radiographic signs of spinal instability.[23,94]

However, several considerations should be considered while performing decompression alone in ADS patients. First, the extent of decompression should be limited to the one or two levels that are mostly responsible for the patient's symptoms. During decompression, the use of minimally invasive techniques causing the least risk to the paraspinal muscles should be employed whenever possible. This strategy was proposed as further means that can limit curve progression when decompression alone is being considered.[8,72] Second, iatrogenic destabilization can follow

Table 3. Lenke–Silva clinical and radiographic classification based categorization of ADS patients for levels of operative treatment.[110]

Symptom	Nonoperative management	Level I	Level II	Level III	Level IV	Level V	Level VI
Neurogenic claudication/ radiculopathy	Minimal	+	+	+	+	+	+
Back pain	Minimal	Minimal	+/-	+	+	+	+
Anterior osteophytes	+	+	-	-	-	-	-
Olisthesis	-	-	-	+	+	+	+
Coronal Cobb < 30º	-	-	-	+	+	+	+
Lumbar kyphosis	-	-	-	-	+	+	+
Global imbalance	-	-	-	-	-	+(flexible)	+(Stiff/fused)

+; present, -: absent.

decompression alone, resulting in accelerated curve progression.[98] To avoid such consequences, one should avoid performing decompression alone at the proximal and distal ends of the curve and at the apex of the curve.[14, 16] Furthermore, one should avoid decompression alone at levels with normal disc height and scarce osteophytes because disc collapse and osteophytes can buffer curve progression, which can be anticipated in their absence.[50] Third, decompression alone should be done when compression is due to a real stenosing element causing direct neural compromise like narrowed canal or foramen or a hypertrophied ligament or joint. Surgeons should bear in mind that deformity itself may cause compression and that indirect decompression via deformity correction is sometimes a better strategy to perform. Fourth, decompression has nothing to do with the disabling axial back pain commonly reported in ADS patients[94] and thus should be avoided in such cases. Finally, ADS patients who underwent decompression alone should be followed up regularly to rule out iatrogenic destabilization and curve progression.

Posterior Decompression with Fusion:

The cornerstone in the surgical management of ADS is deformity correction augmented by posterior fusion with/without adjunctive direct decompression of radiologically confirmed symptomatic stenotic segments. Augmentation of posterior decompression with instrumented fusion is recommended in all curves with the previously mentioned risk factors for curve progression.[94] The use of posterior instrumentation via pedicle screw placement and contoured rods with appropriate release of posterior elements can achieve some 3D correction of the deformity. Curve correction without decompression can indirectly release some neural compression on the concave side and relieve neural traction on the convex side of the curve, in addition to addressing the axial back pain that is commonly associated with ADS. Successful fusion can stop the worsening of spinal instability and progression of the curve. Although fusion can be achieved without instrumentation, fusion in situ cannot correct curves or improve the existing axial back pain. Fusion alone can be implemented in mild stable curves indicated for decompression alone, where the fusion of the segment requiring extensive decompression with potential instability must be considered in the presence of coronal and sagittal balance.[27]

Whereas posterior decompression with fusion in nonrigid or semirigid curves can achieve adequate triplanar correction, rigid curves, especially in the presence of significant coronal imbalance, usually need some anterior release. Correction of curves should consider sagittal balance to the same degree as coronal balance. Correction of LL to match the pelvic incidence as much as possible can reduce the compensatory knee and hip flexion and reduce the energy of ambulation.[68] Pelvic incidence-lumbar lordosis (PI-LL) mismatch is strongly correlated to the sagittal vertical axis (SVA), and both have a strong impact on the global sagittal balance. Sagittal imbalance in ASD is known for its association with increased disability and worsened health-related quality of life.[52,99] So, the goal of corrective surgery should include optimizing PI-LL and SVA to reach a global sagittal balance.[67,105,122] Even with extensive fusion down to the sacrum, the sagittal imbalance can occur if the lumbar spine is fused in hypolordosis, so restoration of LL is of paramount importance to attain and maintain this balance.[26]

The proper selection of fusion level in ADS has a great impact on the results of corrective surgery. Some recognizable criteria help proper determination of fusion level:[3,50,145] a) do not select a tilted upper instrumented vertebra; b) do not stop fusion at the curve apex; c) include junctional kyphosis in the fusion; d) include severe lateral subluxation in the fusion; e) include anterolisthesis and retrolisthesis in the fusion; f) iliac fixation to be considered in long fusions. Whether stopping fusion proximally at the lumbar spine or extending into the thoracic spine is debatable. Most surgeons prefer to extend fusion to T10 to avoid adjacent segment disease with fusions at L1 and provide a more stable proximal point through the attachment of T10 to the rib cage, compared to T11 and T12. Other surgeons argued that adjacent segment disease develops as a degenerative process that cannot be prevented by selecting T10 as a proximal fusion level. [117] Moreover, fusion to the level of T11 or T12 was reported to be acceptable when the upper instrumented vertebra was above the upper-end vertebra. [25] Extension of fusion into the sacrum distally in the presence of a healthy L5-S1 segment is another debatable point. [19, 95] Patients with sagittal imbalance are likely to develop L5-S1 degeneration with deterioration of balance when they get fused to L5 even with healthy preoperative segments. Edwards and colleagues found that 61% of those who were fused to L5 developed subsequent degeneration, sagittal imbalance, and increased risk of reoperations.[38] Extension of fusion to the sacrum is superior to L5 in achieving sagittal correction. To avoid pseudoarthrosis which more commonly associates fusion to the sacrum,[38] additional iliac fixation and L5-S1 interbody fusion are recommended.[24] The addition of iliac screws to the construct with/without sacroiliac arthrodesis can also reduce both axial and rotational loads on the sacroiliac joints and thus avoid late-onset worsening of the axial back pain that associates sacroiliac joint overloading. Although several indications for iliac fixation exist, correction of ASD was found to be the most common.[116]

Augmented Interbody Fusion:

A chief component of curve formation in ADS results from the asymmetrical disc space collapse caused by the asymmetrical degeneration and axial loading.[3,86,94] As a consequence, correction of disc space asymmetry would share to a great extent in the global curve correction. This can be achieved through the insertion of interbody spacers for correction of disc space height and enhancing fusion. These interbody constructs can be introduced through either anterior or posterior approaches. All anterior (ALIF), posterior (PLIF), lateral (LLIF), extreme lateral (XLIF), and axial LIF interbody fusion techniques were described in the literature.[5,54,91] The use of interbody arthrodesis is beneficial in patients at risk of pseudoarthrosis and in long segment fusions, especially at lower lumbar and lumbosacral levels.[118] Anterior and lateral approaches to the spine allow for anterior release, angular correction in sagittal and coronal planes, indirect decompression by restoration of foraminal height, and the use of larger cages with lower subsidence rates.[27,145] Anterior lumbar interbody fusion (ALIF) is particularly suitable for L4-L5 and L5-S1 due to local vascular anatomy; however, visceral and vascular injuries, in addition to retrograde ejaculation, are potential hazards.[79] Lateral lumbar interbody fusion (LLIF) is more suitable for T12-L1 to L4-5 level with the disadvantages of being difficult at the L5-S1 level and carrying the risk of lumbar plexus injury and psoas weakening.[61] Minimally invasive extreme lateral interbody fusion (XLIF) by Ozgur et al. [87] has been introduced as a safe and less invasive approach to performing anterior lumbar fusion. This technique was used by Isaacs and colleagues in 107 patients with ADS either standalone (18.7%), with lateral fixation (5.6%) or with supplemental pedicle screw fixation (75.7%).[56] The authors reported minimized morbidity with the rate of major complications compared favorably to that reported by other studies. On the other hand, posterior approaches for interbody fusion (PLIF) can provide adequate correction of deformity with avoidance of complications related to anterior and lateral approaches. However, significant root retraction and the potential for induced kyphosis if the implant is not placed enough anteriorly are reported disadvantages for that approach.[28,75] The transforaminal interbody fusion (TLIF), on the other side, allows a more anterior insertion of the implant, providing better pivoting for the achievement of lordosis with minimal root retraction. The disadvantages of this approach include the following: facetectomy induced instability mandating pedicle screw placement and contralateral root impingement during compression across ipsilateral rods to achieve lordosis. Another potential hazard reported in the literature is a vascular injury during the rotation of the implant inside the disc space. Implant manipulation in order to lie parallel to the anterior limbus of the endplate can result in a breach of the anterior annulus and vascular injury.[65,97]

Minimally Invasive Surgeries:

Recently, minimally invasive surgeries (MIS) have been developed involving multiple small incisions, applying interbody fusions (e.g., PLIF, TLIF, LLIF, and ALIF) through minimally invasive approaches and using percutaneous pedicle screw fixation.[63,92] Although some studies suggest lower complication rates with MIS compared to open surgery, this was challenged by the fact that cases with more severe deformities tend to undergo open surgery.[29] MIS is known for reduced blood loss, less tissue injury, hence less likely to be followed by severe postoperative pain, and more likely to be associated with shorter hospital stays and fewer pain medications. [129] Moreover, MIS was found to be associated with lower infection rates than those of open surgery due to a lower chance of contamination of limited exposures and shorter hospital stays, resulting in lower risks of nosocomial infections.[90] A systematic review comparing MIS and open surgery in ADS concluded that both approaches can relieve both pain and disability, which are the main concerns of patients preoperatively. Although both MIS and open surgery were comparable regarding their abilities to correct coronal balance, open surgery was found superior in correcting the sagittal deformity.[69] This may be explained by the capability of open surgery to perform aggressive disarticulations and bony osteotomies.[2] However, in view of the comparable achievement of pain and disability improvement by both MIS and open surgery, the more ideal degrees of sagittal correction achieved by open surgery may not outweigh the higher complication rates and are considered by some as being likely not necessary.[81]

Two reported complications for MIS were the increased radiation exposure and the longer operative time. A previous study comparing MIS to open surgery for lumbar discectomy reported 10–20% increase in radiation exposure to the surgeon's thyroid, chest, eyes, and hands.[76] Fortunately, studies that evaluated the learning curve of MIS revealed a progressive reduction in the operative time of later cases compared to initial ones. [129]

Posterior Osteotomies:

Contrary to augmented interbody fusion, which corrects deformity through the relative anterior column and concave side lengthening, posterior osteotomies correct the deformity through posterior column shortening and differential bone removal from the convex versus the concave sides of the curve. In cases having rigid curves (i.e., curves with less than 50% correction in preoperative bending films or intraoperative traction fluoroscopy), the presence of a significant positive sagittal balance indicates osteotomies to restore balance, reduce the burden on bone/hardware interface, and reduce mechanical failure rates.[118] Although these procedures can increase bleeding, surgical time, and perioperative morbidities, they are indicated in certain cases to achieve sagittal balance, which has the highest impact on postoperative outcome.[61] Ideal sagittal balance was defined by SVA <50 mm, PI-LL <10º, and PT <25º.[122] Selection of the level of osteotomy is critical for successful corrective surgery, typically at the level of relative kyphosis and maximum deformity.[103] Furthermore, the most appropriate type of osteotomy per case should be carefully selected as no one-fits-all rule in deformity corrective surgeries.

Smith–Petersen osteotomy (SPO) is an opening wedge osteotomy using the posterior disc space as a hinge with resection of bilateral facet joints, a variable amount of the spinous process and lamina, and the posterior ligaments at the osteotomy site.[126] Several modified versions were described in the literature by Chapelle,[66] Briggs,[20] Wilson[141], and Simmons,[121] all of which are common choices. These osteotomies fulfill 10–15º of correction per level but are more prone to a subsequent loss of correction [150] and vascular injury caused by forced elongation of the anterior column.[100] Ponte osteotomy is a closing osteotomy that was originally described for managing thoracic kyphosis and involved a wide pedicle-to-pedicle resection of facet joints, superior and inferior laminae, and all of ligamentum flavum at every segmental level of the kyphotic region. This osteotomy creates opening gaps of 5–8 mm, extending uniformly along the entire width of the posterior spine allowing later for closure of gaps gradually, starting at the apex and proceeding toward the ends of the curve.[96]

Another example of closing osteotomy is the pedicle subtraction osteotomy (PSO) developed by Thomassen.[131] This is a high-grade three-column osteotomy that removes the posterior elements and a V-shaped wedge of the vertebral body, which is technically more demanding compared to other types. [35] Classic PSO can achieve 30–40 degrees of correction per level.[58] Modifications of PSO by Chen et al.[22] and Zhang at al.[149] have also been described. Cases of ADS with severe global positive sagittal balance and short angular deformity are the best candidates for PSO. Ponte osteotomy is more suitable for a small focal kyphosis or a long smooth deformity. Similarly, SPO can be performed over three or more segments, thus allocating stress to each segment equally and reducing the highly concentrated stress at the anterior aspect of a single level that may cause aortic injury.[100] The bone-disc-bone osteotomy (BDBO) is another 3-column wedge osteotomy, including the disc endplates with/without pedicles. These osteotomies are indicated for a curve with a disc space representing the apex of the curve or containing the center of the rotational axis in the presence of severe positive sagittal balance. The main advantage is its applicability to the lumbar spine, achieving comparable corrections to vertebral column resections with preservation of nerve roots. [37, 88] However, the most powerful and challenging corrective tool for spinal deformity is typically the vertebral column resection (VCR).[70] Owing to its extreme difficulty and the considerable potential complications, it was considered a last resort technique for the most tenacious spinal deformities.[128] During osteotomy, differential wedging of the osteotomy on both sides can also address coronal imbalance simultaneously while correcting the sagittal balance. More bone resection from the convex side can be achieved by creating a longer wedge on the contralateral side and a shorter wedge on the ipsilateral side of coronal imbalance that can correct the coronal deformity when closing this osteotomy at the end of surgery.[21]

Complications of Surgical Management:

Complications of corrective surgeries of ADS can be categorized into four main groups: neurological, skeletal, systemic, and surgical site complications. Neurological complications incorporate pain (somatic and neuropathic), sensory (paresthesias and sensory loss), and motor (weakness and paralysis) deficits. Skeletal complications include pseudoarthrosis, compression fractures, junctional kyphosis, and hardware failure. Associated systemic complications may also ensue during or after hospital stays, such as thromboembolism, acute coronary syndrome, respiratory distress syndrome, venous thromboembolism, and urinary tract infections.[11,94,104] Based on 4,980 cases of ADS surgery submitted to the Scoliosis Research Society (SRS) over three years, at least one perioperative complication developed in 10.5% of cases, with death reported in only 0.3%. Durotomy was the most common reported complication (2.9%), with wound-related complications occurring in 2.4%. [104] In a meta-analysis of 93 articles conducted by Sciubba et al.,[113] the authors reported major perioperative complications in 18.5% and minor complications in 15.7% of patients. Eventually, 20.5% of patients developed long-term radiographic defined or instrumentation related failure such as pseudoarthrosis, proximal junction kyphosis, instrumentation/graft failure, and adjacent segment degeneration.

In a study by Schwab and colleagues, the authors tried to construct a model to predict outcomes and complications after adult deformity surgery. They found that patients more likely to develop complications were those who have very positive sagittal balance, lost LL, or undergone osteotomies and extended fusions down to the sacrum.[110]

However, the positive impact of deformity correction on patient's life may outweigh the negative impact of complications. Patients with intractable pain may be willing to perform high-risk surgeries, hoping to achieve a better quality of life. A previous study demonstrated that complications do not always impact the clinical outcome at 1 year postoperatively. The authors reported similar improvements in Oswestry Disability Index (ODI), Scoliosis Research Society (SRS), and Numeric Pain Rating Scale (NPRS) scores between three groups of complications severity (major, minor, or no complications).[47] A study by Smith et al. reported that although the complication rate in the elderly was higher (71%), they achieved more benefit from corrective surgeries than younger patients who had significantly lower complication rates (17%).[124] This may be explained based on higher baseline disability in the elderly, resulting in less impact of the greater magnitude of surgery and the higher rates of complications on their perception of disability and functionality.

However, it is crucial for a better outcome to select the proper patient who is truly indicated for corrective surgery and benefit the most from this intervention. A study comparing operative to nonoperative management at initial presentation for symptomatic adult scoliosis was conducted in concurrent randomized or observational cohorts. Based on as-treated and minimal clinically important difference (MCID) analyses, the authors advised nonoperative treatment if the patient is satisfied with his current spine-related health, but they understand that improvement is unlikely. However, patients not satisfied with current spine-related health and expect improvement are preferably offered surgery. [60] Despite the complications associated with the extensive nature of deformity corrective surgeries, studies reported an improvement in the quality of life in over 94% of cases.[110,136] This is supported by several studies considering ADS a condition best managed surgically.[27, 60, 98, 118] The worse the baseline disability and the more extensive the corrective surgery and complications, the more the benefit gained from surgical treatment and the more marked the improvement in quality of life reported.[110] On the other hand, patients with psychiatric disorders or tobacco use are those with worse outcome and least improvement regardless of the performed type of surgery.[53] Another factor that was reported to correlate positively with outcome was the degree of fatty degeneration of multifidus muscle measured by MRI on the concave side of the curve. This reflects the importance of improving the condition of paraspinal muscles preoperatively to reduce curve progression and postoperatively to maintain curve correction.[143] Although body mass index (BMI) was found to be a nonsignificant factor impacting outcome or severity of curves by some authors[45,144], others reported greater BMI as a predictor of poor outcomes in both younger and older patients.[125]

SUMMARY AND CONCLUSION

Adult degenerative scoliosis is a spine-related health problem of increasing prevalence owing to the increasing population aging. It is a relatively benign condition with a slowly progressive natural history. Despite the name of the condition, it is a triplanar (coronal, sagittal, and axial) deformity, with the spinopelvic parameters being the most important and exerting the greatest impact on outcomes. Each patient should be approached based on their clinical presentation, associated conditions, and expected outcomes. Treatment strategies vary widely from palliative measures with minimal benefits to extensive corrective surgeries with major complications but a substantial positive impact on quality of life. Contrary to idiopathic scoliosis, Cobb's angles in the coronal plane are not the major role player or surgical targets in corrective surgeries. Other factors like spinal stenosis, spondylolisthesis, laterolisthesis, and sagittal imbalance play more important roles in the severity of the condition and planning for surgery. Minimally invasive techniques can be employed judiciously in a standalone fashion in selected cases or in combination with larger procedures to shorten the duration of surgery and minimize exposures. Larger corrective surgeries, although associated with more complications, are justified for larger deformities as better outcomes were reported. Thorough patient counseling to balance between patient's expectations and surgeon's anticipated outcomes is of utmost importance to ensure postoperative satisfaction.

Recommendations:

Several unresolved topics related to adult degenerative scoliosis are still waiting for prospective well-designed studies. Due to the paucity of randomized controlled studies in the literature, a debate is still ongoing on the best treatment strategies to address this spine-related health problem. Comparisons of the new sagittal realignment braces to surgical correction, combined decompression/fusion to corrective fusions only, minimally invasive versus open conventional surgeries, and various closing and opening spinal osteotomies are all interesting fields of future research. Furthermore, a new multimodal classification system, including various physical, radiographic, and psychological dimensions, is needed. Management of adult degenerative scoliosis should be based on the best currently available literature and directed by patient characteristics and expectations.

REFERENCES

1. Acaroğlu RE, Dede Ö, Pellisé F, Güler ÜO, Domingo-Sàbat M, Alanay A, et al: Adult spinal deformity: a very heterogeneous population of patients with different needs. Acta Orthop Traumatol Turc 50(1):57–62, 2016
2. Adogwa O, Sure DR, LaBagnara M, Shaffrey CI, Fessler RG: Minimally invasive spine surgery and sagittal correction. Neurosurgery 63(Suppl 1):31–36, 2016
3. Aebi M: The adult scoliosis. Eur Spine J 14:925–948, 2005
4. Aebi M, Gunzburg R, Szpalski M: The aging spine. Berlin and New York, NY: Springer, 2005
5. Afathi M, Zairi F, Devos P, Allaoui M, Marinho P, Chopin D, et al: Anterior lumbar sagittal alignment after anterior or lateral interbody fusion. Orthop Traumatol Surg Res 103(8):1245–1250, 2017
6. Ailon T, Smith JS, Shaffrey CI, Lenke LG, Brodke D, Harrop JS, et al: Degenerative spinal deformity. Neurosurgery 77 Suppl 4:S75–S91, 2015
7. Amabile C, Moal B, Chtara OA, Pillet H, Raya JG, Iannessi A, et al: Estimation of spinopelvic muscles' volumes in young asymptomatic subjects: a quantitative analysis. Surg Radiol Anat 39(4):393–403, 2017
8. Anand N, Baron EM, Khandehroo B, Kahwaty S: Long-term 2- to 5-year clinical and functional outcomes of minimally invasive surgery for adult scoliosis. Spine (Phila Pa 1976) 38(18):1566–1575, 2013
9. Anand N, Baron EM, Thaiyananthan G, Khalsa K, Goldstein TB: Minimally invasive multilevel percutaneous correction and fusion for adult lumbar degenerative scoliosis: a technique and feasibility study. J Spinal Disord Tech 21:459–467, 2008
10. Anasetti F, Galbusera F, Aziz HN, Bellini CM, Addis A, Villa T, et al: Spine stability after implantation of an interspinous device: an in vitro and finite element biomechanical study. J Neurosurg Spine 13(5):568–575, 2010
11. Ascani E, Bartolozzi P, Logroscino CA, Marchetti PG, Ponte A, Savini R, et al: Natural history of untreated idiopathic scoliosis after skeletal maturity. Spine (Phila Pa 1976) 11(8):784–789, 1986
12. Barrios C, Lapuente JP, Sastre S: Treatment of chronic pain in adult scoliosis. Stud Health Technol 88:290–303, 2002

13. Benner B, Ehni G: Degenerative lumbar scoliosis. Spine (Phila Pa 1976) 4(6):548–552, 1979
14. Berven SH, Lowe T: The Scoliosis Research Society classification for adult spinal deformity. Neurosurg Clin N Am 18(2):207–213, 2007
15. Bess S, Line B, Fu KM, McCarthy I, Lafage V, Schwab F, et al: The health impact of symptomatic adult spinal deformity: comparison of deformity types to United States population norms and chronic diseases. Spine (Phila Pa 1976) 41(3):224–233, 2016
16. Birknes JK, White AP, Albert TJ, Shaffrey CI, Harrop JS: Adult degenerative scoliosis: a review. Neurosurgery 63(3 Suppl):94–103, 2008
17. Blum CL: Chiropractic and pilates therapy for the treatment of adult scoliosis. J Manipulative Physiol Ther 25:E3, 2002
18. Bradford DS, Tay BK, Hu SS: Adult scoliosis: surgical indications, operative management, complications, and outcomes. Spine (Phila Pa 1976) 24(24):2617–2629, 1999
19. Bridwell KH, Edwards CC 2nd, Lenke LG: The pros and cons to saving the L5-S1 motion segment in a long scoliosis fusion construct. Spine (Phila Pa 1976) 28(20):S234–242, 2003
20. Briggs H, Keats S, Schlesinger PT: Wedge osteotomy of the spine with bilateral intervertebral foraminotomy; correction of flexion deformity in five cases of ankylosing arthritis of the spine. J Bone Joint Surg Am 29:1075–1082, 1947
21. Cecchinato R, Berjano P, Aguirre MF, Lamartina C: Asymmetrical pedicle subtraction osteotomy in the lumbar spine in combined coronal and sagittal imbalance. Eur Spine J 24 Suppl 1:S66-S71, 2015
22. Chen F, Kang Y, Li H, Lv G, Lu C, Li J, et al: Modified pedicle subtraction osteotomy as a salvage method for failed short-segment pedicle instrumentation in the treatment of thoracolumbar fracture. Clin Spine Surg 29(3):E120–E126, 2016
23. Cho KJ, Kim YT, Shin SH, Suk SI: Surgical treatment of adult degenerative scoliosis. Asian Spine J 8(3):371–381, 2014
24. Cho KJ, Suk SI, Park SR, Kim JH, Choi SW, Yoon YH, et al: Arthrodesis to L5 versus S1 in long instrumentation and fusion for degenerative lumbar scoliosis. Eur Spine J 18(4):531–537, 2009
25. Cho KJ, Suk SI, Park SR, Kim JH, Jung JH: Selection of proximal fusion level for adult degenerative lumbar scoliosis. Eur Spine J 22(2):394–401, 2013
26. Cho KJ, Suk SI, Park SR, Kim JH, Kang SB, Kim HS, et al: Risk factors of sagittal decompensation after long posterior instrumentation and fusion for degenerative lumbar scoliosis. Spine (Phila Pa 1976) 35(17):1595–1601, 2010
27. Cho KJ, Suk SI, Park SR, Kim JH, Kim SS, Lee TJ, et al: Short fusion versus long fusion for degenerative lumbar scoliosis. Eur Spine J 17(5):650–656, 2008
28. Cunningham BW, Polly DW Jr: The use of interbody cage devices for spinal deformity: a biomechanical perspective. Clin Orthop Relat Res (394):73–83, 2002
29. Dangelmajer S, Zadnik PL, Rodriguez ST, Gokaslan ZL, Sciubba DM: Minimally invasive spine surgery for adult degenerative lumbar scoliosis. Neurosurg Focus 36:E7, 2014
30. Daubs MD, Lenke LG, Cheh G, Stobbs G, Bridwell KH: Adult spinal deformity surgery: complications and outcomes in patients over age 60. Spine (Phila Pa 1976) 32(20):2238–2244, 2007

31. Davis C, Doerger C, Rowland J, Sauber C, Eaton T: Myofascial release as complementary in physical therapy for two elderly patients with osteoporosis and kyphoscoliosis. J Geriatric Phys Ther 25:33, 2002
32. Diebo BG, Cherkalin D, Jalai CM, Shah NV, Poorman GW, Beyer GA, et al: Comparing psychological burden of orthopaedic diseases against medical conditions: Investigation on hospital course of hip, knee, and spine surgery patients. J Orthop 15:297–301, 2018
33. Diebo BG, Henry J, Lafage V, Berjano P: Sagittal deformities of the spine: factors influencing the outcomes and complications. Eur Spine J 24:S3–15, 2015
34. Diebo BG, Lavian JD, Murray DP, Liu S, Shah NV, Beyer GA, et al: The impact of comorbid mental health disorders on complications following adult spinal deformity surgery with minimum 2-year surveillance. Spine (Phila Pa 1976) 43:1176–1183, 2018
35. Diebo B, Liu S, Lafage V, Schwab F: Osteotomies in the treatment of spinal deformities: indications, classification, and surgical planning. Eur J Orthop Surg Traumatol 24 Suppl 1:S11–S20, 2014
36. Diebo BG, Shah NV, Boachie-Adjei O, Zhu F, Rothenfluh DA, Paulino CB, et al: Adult spinal deformity. Lancet 394:160–172, 2019
37. Domanic U, Talu U, Dikici F, Hamzaoglu A: Surgical correction of kyphosis: posterior total wedge resection osteotomy in 32 patients. Acta Orthop Scand 75:449–455, 2004
38. Edwards CC 2nd, Bridwell KH, Patel A, Rinella AS, Jung Kim Y, Berra AB, et al: Thoracolumbar deformity arthrodesis to L5 in adults: the fate of the L5-S1 disc. Spine (Phila Pa 1976) 28(18):2122–2131, 2003
39. Everett CR, Patel PK: A systematic literature review of nonsurgical treatment in adult scoliosis. Spine 32(19 Suppl):S130–S134, 2007
40. Faldini C: Le scoliosi degenerative. Timeo Editore, Bologna, Italy, 2009
41. Faldini C, Pagkrati S, Grandi G, Di Gennaro V, Faldini O, Giannini S: Degenerative lumbar scoliosis: features and surgical treatment. J Orthop Traumatol 7:67–71, 2006
42. Fehlings MG, Tetreault L, Nater A, Choma T, Harrop J, Mroz T, et al: The aging of the global population: the changing epidemiology of disease and spinal disorders. Neurosurgery 77(suppl 4): S1–S5, 2015
43. Foley KT, Holly LT, Schwender JD: Minimally invasive lumbar fusion. Spine (Phila Pa 1976) 28(15 Suppl):S26–S35, 2003
44. Fritz JM, Whitman JM, Childs JD: Lumbar spine segmental mobility assessment: an examination of validity for determining intervention strategies in patients with low back pain. Arch Phys Med Rehabil 86(9):1745–1752, 2005
45. Fu L, Chang MS, Crandall DG, Revella J: Does obesity affect surgical outcomes in degenerative scoliosis? Spine (Phila Pa 1976) 39(24):2049–2055, 2014
46. Glassman SD, Berven S, Bridwell K, Horton W, Dimar JR: Correlation of radiographic parameters and clinical symptoms in adult scoliosis. Spine (Phila Pa 1976) 30:682–688, 2005
47. Glassman SD, Hamill CL, Bridwell KH, Schwab FJ, Dimar JR, Lowe TG: The impact of perioperative complications on clinical outcome in adult deformity surgery. Spine (Phila Pa 1976) 32(24):2764–2770, 2007
48. Grubb SA, Lipscomb HJ, Coonrad RW: Degenerative adult onset scoliosis. Spine (Phila Pa 1976) 13:241–245, 1988
49. Guigui P, Devyver B, Rillardon L, Ngounou P, Deburge A, Ghosez JP: Intraoperative and early postoperative complications of lumbar and lumbosacral fusion: prospective analysis of 872 patients. Rev Chir Orthop Reparatrice Appar Mot 90(1):5–15, 2004 (French)

50. Gupta MC: Degenerative scoliosis. Options for surgical management. Orthop Clin North Am 34:269–279, 2003
51. Haldeman S, Nordin M, Chou R, Côté P, Hurwitz EL, Johnson CD, et al: The Global Spine Care Initiative: World Spine Care executive summary on reducing spine-related disability in low- and middle-income communities. Eur Spine J 27(Suppl 6):776–785, 2018
52. Harroud A, Labelle H, Joncas J, Mac-Thiong JM: Global sagittal alignment and health-related quality of life in lumbosacral spondylolisthesis. Eur Spine J 22:849–856, 2013
53. Hostin R, McCarthy I, O'Brien M, Bess S, Line B, Boachie-Adjei O, et al: Incidence, mode, and location of acute proximal junctional failures after surgical treatment of adult spinal deformity. Spine (Phila Pa 1976) 38(12):1008–1015, 2013
54. Hsieh MK, Chen LH, Niu CC, Fu TS, Lai PL, Chen WJ: Combined anterior lumbar interbody fusion and instrumented posterolateral fusion for degenerative lumbar scoliosis: indication and surgical outcomes. BMC Surg 15:26, 2015
55. Illés T, Somoskeöy S: The EOS™ imaging system and its uses in daily orthopaedic practice. Int Orthop 36(7):1325–1331, 2012
56. Isaacs RE, Hyde J, Goodrich JA, Rodgers WB, Phillips FM: A prospective, nonrandomized, multicenter evaluation of extreme lateral interbody fusion for the treatment of adult degenerative scoliosis: perioperative outcomes and complications. Spine (Phila Pa 1976) 35(26 Suppl):S322–330, 2010
57. Jackson RP, McManus AC: Radiographic analysis of sagittal plane alignment and balance in standing volunteers and patients with low back pain matched for age, sex, and size. A prospective controlled clinical study. Spine (Phila Pa 1976) 19(14):1611–1618, 1994
58. Jaffray D, Becker V, Eisenstein S: Closing wedge osteotomy with transpedicular fixation in ankylosing spondylitis. Clin Orthop Relat Res (279):122–126, 1992
59. Kelly A, Younus A, Lekgwara P: Adult degenerative scoliosis – A literature review. Interdiscip Neurosurg 20:100661, 2020
60. Kelly MP, Lurie JD, Yanik EL, Shaffrey CI, Baldus CR, Boachie-Adjei O, et al: Operative Versus Nonoperative Treatment for Adult Symptomatic Lumbar Scoliosis. J Bone Joint Surg Am 101(4):338–352, 2019
61. Kim W, Porrino JA, Hood KA, Chadaz TS, Klauser AS, Taljanovic MS: Clinical evaluation, imaging, and management of adolescent idiopathic and adult degenerative scoliosis. CurrProbl Diagn Radiol 48(04):402–414, 2019
62. Kosaka H, Sairyo K, Biyani A, Leaman D, Yeasting R, Higashino K, et al: Pathomechanism of loss of elasticity and hypertrophy of lumbar ligamentum flavum in elderly patients with lumbar spinal canal stenosis. Spine (Phila Pa 1976) 32(25):2805–2811, 2007
63. Kulkarni A, Bohra H, Dhruv A, Sarraf A, Bassi A, Patil V: Minimal invasive transforaminal lumbar interbody fusion versus open transforaminal lumbar interbody fusion. Indian J Orthop 50: 464–472, 2016
64. Kwan KYH, Naresh-Babu J, Jacobs W, de Kleuver M, Polly DW, Yilgor C, et al: Toward the development of a comprehensive clinically oriented patient profile: A systematic review of the purpose, characteristic, and methodological quality of classification systems of adult spinal deformity. Neurosurgery 88(6):1065–1073, 2021
65. Kwon BK, Berta S, Daffner SD, Vaccaro AR, Hilibrand AS, Grauer JN, et al: Radiographic analysis of transforaminal lumbar interbody fusion for the treatment of adult isthmic spondylolisthesis. J Spinal Disord Tech 16(5):469–476, 2003

66. La Chapelle: Osteotomy of the lumbar spine for correction of kyphosis in a case of ankylosing spondylarthritis. J Bone Joint Surg Am 28:851–858, 1946
67. Lafage R, Schwab F, Challier V, Henry JK, Gum J, Smith J, et al: Defining spino-pelvic alignment thresholds: should operative goals in adult spinal deformity surgery account for age? Spine (Phila Pa 1976) 41(1):62–68, 2016
68. Lafage V, Schwab F, Patel A, Hawkinson N, Farcy JP: Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. Spine (Phila Pa 1976) 34(17):E599–E606, 2009
69. Lak AM, Lamba N, Pompilus F, Yunusa I, King A, Sultan I, et al: Minimally invasive versus open surgery for the correction of adult degenerative scoliosis: a systematic review. Neurosurg Rev 44(2):659–668, 2021
70. Lenke LG, Sides B, Koester L, Hensley M, Blanke KM: Surgical technique: Vertebral column resection (VCR) for severe pediatric and adult spinal deformity. Scoliosis Research Society Paper 13. (Russell Hibbs Award, Best clinical Presentation) 42nd annual meeting, Edinburgh, Scotland, 2007
71. Lindbäck Y, Tropp H, Enthoven P, Abbott A, Öberg B: PREPARE: presurgery physiotherapy for patients with degenerative lumbar spine disorder: a randomized controlled trial. Spine J 18:1347–1355, 2018
72. Lonstein JE: Scoliosis: surgical versus nonsurgical treatment. Clin Orthop Relat Res 443:248–259, 2006
73. Lutz W, Sanderson W, Scherbov S: The coming acceleration of global population aging. Nature 451:716–719, 2008
74. Mac-Thiong JM, Roussouly P, Berthonnaud E, Guigui P: Sagittal parameters of global spinal balance: normative values from a prospective cohort of seven hundred nine Caucasian asymptomatic adults. Spine (Phila Pa 1976) 35(22):E1193–E1198, 2010
75. Madan S, Boeree NR: Outcome of posterior lumbar interbody fusion versus posterolateral fusion for spondylolytic spondylolisthesis. Spine (Phila Pa 1976) 27(14):1536–1542, 2002
76. Mariscalco MWMY, Takayuki MD, Steinmetz MP, Krishnaney AA, Lieberman IH, Mroz TE: Radiation exposure to the surgeon during open lumbar microdiscectomy and minimally invasive microdiscectomy: a prospective, controlled trial. Spine 36(3): 255–260, 2011
77. Marty-Poumarat C, Scattin L, Marpeau M, Garreau de Loubresse C, Aegerter P: Natural history of progressive adult scoliosis. Spine (Phila Pa 1976) 32:1227–1235, 2007
78. Moal B, Bronsard N, Raya JG, Vital JM, Schwab F, Skalli W, et al: Volume and fat infiltration of spino-pelvic musculature in adults with spinal deformity. World J Orthop 6(9):727–737, 2015
79. Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ: Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg 1(1):2–18, 2015
80. Morningstar MW, Woggon D, Lawrence G: Scoliosis treatment using a combination of manipulative and rehabilitative therapy: a retrospective case series. BMC Musculoskelet Disord 5:32, 2004
81. Mummaneni PV, Park P, Shaffrey CI, Wang MY, Uribe JS, Fessler RG, et al: The MISDEF2 algorithm: an updated algorithm for patient selection in minimally invasive deformity surgery. J Neurosurg Spine 32:1–8, 2019
82. Negrini A, Negrini MG, Donzelli S, Romano M, Zaina F, Negrini S: Scoliosis-Specific exercises can reduce the progression of severe curves in adult idiopathic scoliosis: a long-term cohort study. Scoliosis 10:20, 2015
83. Negrini S, Donzelli S, Aulisa AG, Czaprowski D, Schreiber S, de Mauroy JC, et al: 2016 SOSORT guidelines: orthopaedic and

rehabilitation treatment of idiopathic scoliosis during growth. Scoliosis Spinal Disord 13:3, 2018

84. Nielsen PR, Andreasen J, Asmussen M, Tønnesen H: Costs and quality of life for prehabilitation and early rehabilitation after surgery of the lumbar spine. BMC Health Serv Res 8:209, 2008
85. Nielsen PR, Jørgensen LD, Dahl B, Pedersen T, Tønnesen H: Prehabilitation and early rehabilitation after spinal surgery: randomized clinical trial. Clin Rehabil 24:137–148, 2010
86. Oskouian RJ Jr, Shaffrey CI: Degenerative lumbar scoliosis. Neurosurg Clin N Am 17(3):299–315, 2006
87. Ozgur BM, Aryan HE, Pimenta L, Taylor WR: Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J 6(4):435–443, 2006
88. Ozturk C, Alanay A, Ganiyusufoglu K, Karadereler S, Ulusoy L, Hamzaoglu A: Short-term X-ray results of posterior vertebral column resection in severe congenital kyphosis, scoliosis, and kyphoscoliosis. Spine (Phila Pa 1976) 37(12):1054–1057, 2012
89. Özyemişci Taşkıran Ö: Rehabilitation in adult spinal deformity. Turk J Phys Med Rehabil 66(3):231–243, 2020
90. Parker SL, Adogwa O, Witham TF, Aaronson OS, Cheng J, McGirt MJ: Post-operative infection after minimally invasive versus open transforaminal lumbar interbody fusion (TLIF): literature review and cost analysis. Minim Invasive Neurosurg 54:33–37, 2011
91. Phan K, Huo YR, Hogan JA, Xu J, Dunn A, Cho SK, et al: Minimally invasive surgery in adult degenerative scoliosis: a systematic review and meta-analysis of decompression, anterior/lateral and posterior lumbar approaches. J Spine Surg 2(2):89–104, 2016
92. Phan K, Rao PJ, Scherman DB, Dandie G, Mobbs RJ: Lateral lumbar interbody fusion for sagittal balance correction and spinal deformity. J Clin Neurosci 22:1714–1721, 2015
93. Ploumis A, Transfeldt EE, Gilbert TJ, Mehbod AA, Pinto MR, Denis F: Radiculopathy in degenerative lumbar scoliosis: correlation of stenosis with relief from selective nerve root steroid injections. Pain Med 12(1):45–50, 2011
94. Ploumis A, Transfledt EE, Denis F: Degenerative lumbar scoliosis associated with spinal stenosis. Spine J 7(4):428–436, 2007
95. Polly DW Jr, Hamill CL, Bridwell KH: Debate: to fuse or not to fuse to the sacrum, the fate of the L5-S1 disc. Spine (Phila Pa 1976) 31(19 Suppl):S179–S184, 2006
96. Ponte A, Orlando G, Siccardi GL: The true Ponte osteotomy: by the one who developed it. Spine Deform 6(1):2–11, 2018
97. Potter BK, Freedman BA, Verwiebe EG, Hall JM, Polly DW Jr, Kuklo TR: Transforaminal lumbar interbody fusion: clinical and radiographic results and complications in 100 consecutive patients. J Spinal Disord Tech 18(4):337–346, 2005
98. Pritchett JW, Bortel DT: Degenerative symptomatic lumbar scoliosis. Spine (Phila Pa 1976) 18(6):700–703, 1993
99. Protopsaltis T, Schwab F, Bronsard N, Smith JS, Klineberg E, Mundis G, et al: TheT1 pelvic angle, a novel radiographic measure of global sagittal deformity, accounts for both spinal inclination and pelvic tilt and correlates with health-related quality of life. J Bone Joint Surg Am 96:1631–1640, 2014
100. Püschel J, Zielke K: Korrekturoperation bei Bechterew-Kyphose-Indikation, Technik, Ergebnisse. Zeitschrift für Orthopädie und Unfallchirurgie 120:338–342, 1982

101. Routh RH, Rumancik S, Pathak RD, Burshell AL, Nauman EA: The relationship between bone mineral density and biomechanics in patients with osteoporosis and scoliosis. Osteoporos Int 16 (12):1857–1863, 2005
102. Rushton A, White L, Heap A, Heneghan N: Evaluation of current surgeon practice for patients undergoing lumbar spinal fusion surgery in the United Kingdom. World J Orthop 6:483–490, 2015
103. Sansur CA, Fu KM, Oskouian RJ Jr, Jagannathan J, Kuntz C 4th, Shaffrey CI: Surgical management of global sagittal deformity in ankylosing spondylitis. Neurosurg Focus 24(1):E8, 2008
104. Sansur CA, Smith JS, Coe JD, Glassman SD, Berven SH, Polly DW Jr, et al: Scoliosis research society morbidity and mortality of adult scoliosis surgery. Spine (Phila Pa 1976) 36(9):E593–597, 2011
105. Schwab F, Blondel B, Bess S, Hostin R, Shaffrey CI, Smith JS, et al: Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: a prospective multicenter analysis. Spine (Phila Pa 1976) 38(13):E803–E812, 2013
106. Schwab F, Dubey A, Gamez L, El Fegoun AB, Hwang K, Pagala M, et al: Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. Spine (Phila Pa 1976) 30(9):1082–1085, 2005
107. Schwab F, Dubey A, Pagala M, Gamez L, Farcy JP: Adult scoliosis: a health assessment analysis by SF-36. Spine (Phila Pa 1976) 28:602–606, 2003
108. Schwab F, Farcy JP, Bridwell K, Berven S, Glassman S, Harrast J, et al: A clinical impact classification of scoliosis in the adult. Spine (Phila Pa 1976) 31:2109–2114, 2006
109. Schwab F, Lafage V, Farcy JP, Bridwell K, Glassman S, Ondra S, et al: Surgical rates and operative outcome analysis in thoracolumbar and lumbar major adult scoliosis: application of the new adult deformity classification. Spine (Phila Pa 1976) 32(24):2723–2730, 2007
110. Schwab F, Lafage V, Farcy JP, Bridwell KH, Glassman S, Shainline MR: Predicting outcome and complications in the surgical treatment of adult scoliosis. Spine (Phila Pa 1976) 33(20):2243–2247, 2008
111. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V: Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. Spine (Phila Pa 1976) 35(25):2224–2231, 2010
112. Schwab F, Ungar B, Blondel B, Buchowski J, Coe J, Deinlein D, et al: Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. Spine (Phila Pa 1976) 37(12):1077–1082, 2012
113. Sciubba DM, Yurter A, Smith JS, Kelly MP, Scheer JK, Goodwin CR, et al: A comprehensive review of complication rates after surgery for adult deformity: A reference for informed consent. Spine Deform 3(6):575–594, 2015
114. Sengupta D: Adult spinal deformity, in: Rao R, Smuck M (eds): Orthopaedic Knowledge Update: Spine. 4th ed. Rosemont, IL: American Academy of Orthopaedic Surgeons. 2012; pp 349–367
115. Sengupta DK, Herkowitz HN: Lumbar spinal stenosis. Treatment strategies and indications for surgery. Orthop Clin North Am 34(2):281–295, 2003
116. Shen FH, Mason JR, Shimer AL, Arlet VM: Pelvic fixation for adult scoliosis. Eur Spine J 22(Suppl 2):S265–S275, 2013
117. Shufflebarger H, Suk SI, Mardjetko S: Debate: determining the upper instrumented vertebra in the management of adult degenerative

scoliosis: stopping at T10 versus L1. Spine (Phila Pa 1976) 31(19 Suppl):S185–S194, 2006
118. Silva FE, Lenke LG: Adult degenerative scoliosis: evaluation and management. Neurosurg Focus 28(3):E1, 2010
119. Simmons ED Jr, Simmons EH: Spinal stenosis with scoliosis. Spine (Phila Pa 1976) 17:S117–S120, 1992
120. Simmons ED: Surgical treatment of patients with lumbar spinal stenosis with associated scoliosis. Clin Orthop Relat Res 384:45–53, 2001
121. Simmons EH: Kyphotic deformity of the spine in ankylosing spondylitis. Clin Orthop Relat Res 128:65–77, 1977
122. Smith JS, Klineberg E, Schwab F, Shaffrey CI, Moal B, Ames CP, et al: Change in classification grade by the SRS-Schwab Adult Spinal Deformity Classification predicts impact on health-related quality of life measures: prospective analysis of operative and nonoperative treatment. Spine (Phila Pa 1976) 38(19):1663–1671, 2013
123. Smith JS, Shaffrey CI, Bess S, Shamji MF, Brodke D, Lenke LG, et al: Recent and emerging advances in spinal deformity. Neurosurgery 80:S70–85, 2017
124. Smith JS, Shaffrey CI, Glassman SD, Berven SH, Schwab FJ, Hamill CL, et al: Risk-benefit assessment of surgery for adult scoliosis: an analysis based on patient age. Spine (Phila Pa 1976) 36(10):817–824, 2011
125. Smith JS, Shaffrey CI, Glassman SD, Carreon LY, Schwab FJ, Lafage V, et al: Clinical and radiographic parameters that distinguish between the best and worst outcomes of scoliosis surgery for adults. Eur Spine J 22(2):402–410, 2013
126. Smith-Petersen MN, Larson CB, Aufranc OE: Osteotomy of the spine for correction of flexion deformity in rheumatoid arthritis. Clin Orthop Relat Res 66:6–9, 1969
127. Sparrey CJ, Bailey JF, Safaee M, Clark AJ, Lafage V, Schwab F, et al: Etiology of lumbar lordosis and its pathophysiology: a review of the evolution of lumbar lordosis, and the mechanics and biology of lumbar degeneration. Neurosurg Focus 36(5):E1, 2014
128. Suk SI, Chung ER, Lee SM, Lee JH, Kim SS, Kim JH: Posterior vertebral column resection in fixed lumbosacral deformity. Spine (Phila Pa 1976) 30(23):E703–E710, 2005
129. Sun ZJ, Li WJ, Zhao Y, Qiu GX: Comparing minimally invasive and open transforaminal lumbar interbody fusion for treatment of degenerative lumbar disease: a meta-analysis. Chin Med J 126:3962–3971, 2013
130. Terran J, Schwab F, Shaffrey CI, Smith JS, Devos P, Ames CP, et al: The SRS-Schwab adult spinal deformity classification: assessment and clinical correlations based on a prospective operative and nonoperative cohort. Neurosurgery 73(4):559–568, 2013
131. Thomasen E: Vertebral osteotomy for correction of kyphosis in ankylosing spondylitis. Clin Orthop Relat Res 194:142–152, 1985
132. Vanderpool DW, James JI, Wynne-Davies R: Scoliosis in the elderly. J Bone Joint Surg Am 51(3):446–455, 1969
133. van Erp RMA, Jelsma J, Huijnen IPJ, Lundberg M, Willems PC, Smeets RJEM: Spinal surgeons' opinions on pre- and postoperative rehabilitation in patients undergoing lumbar spinal fusion surgery: A survey-based study in the Netherlands and Sweden. Spine (Phila Pa 1976) 43:713–719, 2018
134. Vernon-Roberts B, Moore RJ, Fraser RD: The natural history of age-related disc degeneration: the influence of age and pathology on cell populations in the L4-L5 disc. Spine (Phila Pa 1976) 33(25):2767–2773, 2008

135. Vialle R, Levassor N, Rillardon L, Templier A, Skalli W, Guigui P: Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. J Bone Joint Surg Am 87(2):260–267, 2005
136. Watanabe K, Lenke LG, Bridwell KH, Kim YJ, Koester L, Hensley M: Proximal junctional vertebral fracture in adults after spinal deformity surgery using pedicle screw constructs: analysis of morphological features. Spine (Phila Pa 1976) 35(2):138-145, 2010
137. Weiss HR, Dallmayer R: Brace treatment of spinal claudication in an adult with lumbar scoliosis- a case report. Stud Health Technol 123:586–589, 2006
138. Weiss HR, Dallmayer R, Stephan C: First results of pain treatment in scoliosis patients using a sagittal realignment brace. Stud Health Technol 123:582–585, 2006
139. Weiss HR, Turnbull D: Brace treatment for adults with spinal deformities, in Bettany-Saltikov J Kandasamy G (eds): Spinal Deformities in Adolescents, Adults and Older Adults. IntechOpen, 2020; doi:10.5772/intechopen.92321
140. Weiss HR, Werkmann M: Treatment of chronic low back pain in patients with spinal deformities using a sagittal re-alignment brace. Scoliosis 4:7, 2009
141. Wilson PJ, Levine DB: Compensatory pelvic osteotomy for ankylosing spondylitis. A case report. J Bone Joint Surg Am 51:142–148, 1969
142. World Population Aging, 1950–2050. New York, NY: United Nations, 2017. https://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2017_Report.pdf.
143. Xie D, Zhang J, Ding W, Yang S, Yang D, Ma L, et a: Abnormal change of paravertebral muscle in adult degenerative scoliosis and its association with bony structural parameters. Eur Spine J 28(7):1626–1637, 2019
144. Xu L, Sun X, Huang S, Zhu Z, Qiao J, Zhu F, et al: Degenerative lumbar scoliosis in Chinese Han population: prevalence and relationship to age, gender, bone mineral density, and body mass index. Eur Spine J 22(6):1326–1331, 2013
145. York PJ, Kim HJ: Degenerative Scoliosis. Curr Rev Musculoskelet Med 10(04):547–558, 2017
146. Youssef JA, Orndorff DO, Patty CA, Scott MA, Price HL, Hamlin LF, et al: Current status of adult spinal deformity. Global Spine J 3(1):51–62, 2013
147. Yue J, Guyer RD, Johnson JP, Khoo LT, Hochschuler SH: The comprehensive treatment of the aging spine: minimally invasive and advanced techniques, 1st edn. Philadelphia, PA: Saunders/Elsevier, 2011
148. Zaina F, Poggio M, Donzelli S, Negrini S: Can bracing help adults with chronic back pain and scoliosis? Short-term results from a pilot study. Prosthet Orthot Int 42(4):410–414, 2018
149. Zhang X, Hu W, Yu J, Wang Z, Wang Y: An effective treatment option for Kümmell disease with neurological deficits: Modified transpedicular subtraction and disc osteotomy combined with long-segment fixation. Spine (Phila Pa 1976) 41(15):E923–E930, 2016
150. Zhu Z, Wang X, Qian B, Wang B, Yu Y, Zhao Q, et al: Loss of correction in the treatment of thoracolumbar kyphosis secondary to ankylosing spondylitis: a comparison between Smith-Petersen osteotomies and pedicle subtraction osteotomy. J Spinal Disord Tech 25(7):383–390, 2012

LIST OF ABBREVIATIONS:

ASD: Adult spinal deformity
ADS: Adult degenerate scoliosis
AIS: Adolescent idiopathic scoliosis
PI: Pelvic incidence
LL: Lumbar lordosis
PT: Pelvic tilt
SS: Sacral slope
SVA: Sagittal vertical axis
SRS: Scoliosis Research Society
SF-36: 36-item Short Form Heath Survey
PCS: Physical component summary
CSVL: Central sacral vertical line
SOSORT: Scoliosis Orthopaedic & Rehabilitation Treatment
MIS: Minimally invasive surgery
SPO: Smith–Petersen osteotomy
PSO: Pedicle subtraction osteotomy
BDBO: Bone-disc-bone osteotomy
VCR: Vertebral column resection
ODI: Oswestry Disability Index
NPRS: Numeric Pain Rating Scale
MCID: Minimal clinically important difference
BMI: Body mass index.

الملخص العربي

الجنف التنكسي للبالغين: مراجعة أدبية للمفاهيم الحالية والاتجاهات الجديدة

البيانات الخلفية: يعتبر الجنف التنكسي في البالغين من المشكلات الصحية المتزايدة نظرا للزيادة المطردة في الأعمار على مستوى العالم. و هي مشكلة صحية حميدة الخاصية لكنها تتطور ببطء بطبيعتها.

الغرض: مراجعة و عرض أحدث المفاهيم الطبية و الخيارات الجراحية المتاحة بالمطبوعات و الدراسات الطبية المرجعية

تصميم الدراسة: مراجعة وصفية للإنتاج الطبي البحثي.

المرضى والطرق: تم البحث عن المراجع والمقالات الطبية ذات الصلة عن طريق قاعدة بيانات بابميد ثم اختيار أنسبها لموضوع البحث

النتائج: رغم ما يوحي به الاسم من حدوث انحناء تاجي فإنه الجنف التنكسي في البالغين يمثل تشوها ثلاثي الأبعاد تلعب فيه المعالم الحوضية الشوكية الدور الأبرز في تحديد النتائج. و يحتاج كل مريض لأسلوب خاص للتقييم و العلاج اعتمادا على الظواهر السريرية، المشاكل المصاحبة و التوقعات المرجوة. و تتفاوت استراتيجيات العلاج من علاجات الطيفية ذات تأثير محدود إلى علاجات جراحية تصحيحية ذات مضاعفات كبيرة محتملة لكنها ذات تأثير إيجابي عظيم على جودة الحياة. و على عكس الجنف غير معلوم العلة الخاص بالمراهقين، فإن درجة الاعوجاج التاجية في الجنف التنكسي ليست بذات الأهمية ولا تمثل الهدف الجراحي الأساسي للتصحيح. بينما عوامل أخرى مثل ضيق القناة الشوكية، و الانزياح الفقاري، و اختلال الاتزان السهمي تلعب الدور الأكبر في تشكيل شدة المرض و تحديد أهداف الجراحة.

و تمثل الجراحات ذات التدخل المحدود دورا هاما حيث يمكن استخدامها بشكل منفرد في بعض الحالات المنتقاة، أو بشكل إضافي مع الجراحات الكبيرة للمساعدة في تقليص المدة الزمنية للجراحة، و تقليص الاستعراض الجراحي. ورغم أن الجراحات التصحيحية الكبرى يصاحبها عدد أكبر من المضاعفات، فإنها تقدم نتائج أفضل.

الخلاصة: من الضروري اعتبار كل مريض حالة خاصة تحتاج إلى استنصاح دقيق لعمل توازن بين تطلعات المريض و توقعات الجراح للوصول لأعلى درجات الرضا بعد الجراحة. و ما زال الإنتاج الفكري الطبي يحتاج لمزيد من الأبحاث لتحديد أنماط العلاج الأنسب و الأعلى فاعلية.