DEGENERATIVE SCOLIOSIS: LITERATURE REVIEW

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The paper presents a review of the current literature concerning the problem of degenerative scoliosis, its clinical manifestations, diagnosis, classification and approaches to surgical treatment. In connection with the aging of the population, improvement of surgical techniques and advance in anesthetic support, the problem of degenerative scoliosis is increasingly viewed with regard to possible options for its surgical correction. There are several factors that contribute to the formation of de novo scoliosis. They involve the facet joint tropism, asymmetric degeneration of the intervertebral disc, osteoporosis, myopathy, and long-existing antalgic scoliosis. Conservative treatment of degenerative scoliosis includes administration of non-steroidal anti-inflammatory drugs, brace treatment, and epidural and paravertebral glucocorticosteroid injections. When conservative therapy is fully ineffective and patient's quality of life significantly decreases, the surgical treatment decision is made individually. The main issue of surgery is the choice of optimal surgical strategy which depends on careful evaluation of clinical symptoms and their pathologic substrate, and mandatory accounting for parameters of the global spinal-pelvic balance. Positive sagittal imbalance is associated with a significant reduction in quality of life, therefore it should be, whenever possible, surgically corrected.
Key Words: spinal deformity, scoliosis adult degenerative scoliosis, secondary scoliosis.

Please cite this paper as: *Vasilyev AI. Degenerative scoliosis: literature review. Hir. Pozvonoc. 2016;13(4):56–65. In Russian. DOI: http://dx.doi.org/10.14531/ss2016.4.56-65.*

Scoliosis is a complex three-dimensional rotatory deformity of the spine in the coronal, sagittal and axial planes. Adult scoliosis or degenerative scoliosis *(de novo)* is a spinal deformity in patients who have reached skeletal maturity with a Cobb angle of more than 10° in the coronal plane [5].

The average incidence of scoliosis is 7.2 % among adults, and in recent decades there has been a tendency to an increase of this indicator [6]. According to foreign studies, the incidence is within 2 to 32 % and may reach 68 % [40]. The patient addresses to the doctor mostly due to complaints of severe pain, often leading to disability [10].

Considering the demographic shift towards increasing the share of the elderly population and an increased focus on the quality of life of people, degenerative scoliosis today is a serious public health issue. Improved diagnostic facilities, surgical equipment and instrumentation, use of modern anesthetic machines have enhanced significantly detection of pathological changes in the spine and have expanded options for their surgical correction. This is especially relevant in terms of the elder aged patients, when the patient usually has a number of comorbidities.

The purpose of the study is to present modern views on etiology, pathogenesis, and possible variants of classifications and treatment methods of degenerative scoliosis.

Definition and etiology

In the literature, the term "degenerative scoliosis" is interpreted ambiguously. In particular, Aebi [7] defines any clinically manifested scoliosis in adults as degenerative scoliosis and separates it into primary or secondary types. Other authors [1, 19, 33, 34] differentiate degenerative or *de novo* scoliosis from idiopathic scoliosis of adults. In any case, most authors consider common approaches to the surgical treatment of deformities, regardless of their etiology due to similar pathogenetic mechanisms of *de novo* scoliosis appearance and progression of idiopathic scoliosis.

In a prospective cohort study in 2006, Kobayashi et al. [19] studied the incidence of *de novo* scoliosis. The object of the study was 60 subjects (18 men and 42 women) aged 50–84 years and without scoliosis at baseline and who were periodically subjected to radiography for a mean of 12 years. *De novo* scoliosis with a Cobb angle of 10 to 18° occurred in 22 (36.7 %) patients. All patients had curvature in the lumbar spine (10 curvatures of the lumbar spine and 9 combined curvatures, in the thoracic and lumbar spine), with the exception of three women with the curvature in the thoracic spine, who had significant osteoporosis and a fracture at least in one vertebra. A more than 20 % decrease in unilateral disc height or more than 5 mm longer osteophyte on one side led to increased incidence of *de novo* scoliosis [19]. These data confirm the views that degenerative scoliosis begins with disc degeneration.

In another study, the authors monitored the influence of the following factors on the development of *de novo* scoliosis: osteoporosis, spondyloarthrosis, compression fractures, spinal stenosis, endochondral anomalies, and violations of the facet joints tropism [16]. However, they did not prove any direct connection of the investigated factors to the development of *de novo* scoliosis.

Benoist [8] put forward the hypothesis that aging can cause degenerative myopathy leading to rupture of spinal balance and gradual kyphotic spinal deformity. Repeated torsional loads may gradually provoke rotatory deformity of the posterior vertebral elements and cause the development of degenerative rotatory scoliosis.

Degenerative spondylolisthesis is a common phenomenon in patients with degenerative scoliosis. According to one study, 55 % of patients with degenerative scoliosis had degenerative spondylolisthesis [35]. The incidence of rotatory spondylolisthesis (antelaterospondylolisthesis) is 13–34 % in adult patients with scoliosis [33]. This condition develops most often at the level of L3–L4, in women and increases with age and curve magnitude. This is a triaxial deformity formed by axial rotation in the vertical axis, lateral displacement toward the curve convexity, and rotation in the sagittal axis [49].

According to the theory proposed by Kebaish [16], *de novo* scoliosis may develop due to foraminal compression of a radicular nerve, which leads to antalgic scoliosis, at first functional scoliosis. But during the long-term compression, the deformity may become structural and begin to progress.

Epidemiology

The prevalence of degenerative scoliosis, according to different authors [19, 39, 50, 53], ranges from 6 to 68 % and increases with age. Pritchett and Bortel [35] studied 200 patients older than 50 years (70 % of them were women) with late onset scoliosis. They found that most of the degenerative lumbar curvatures did not exceed 60° of the Cobb angle and progressed on average by 3° per year. The factors in predicting curve progression were apical vertebral rotation according to Nash – Moe grade III and more, the Cobb angle of curve more than 30°, laterospondylolisthesis of 6 mm or more, the prominence of L5 in relation to the intercrest line. Murata et al. [31] showed that at the early stage, degenerative curvatures could also regress due to wedge-shaped deformity of the intervertebral discs or vertebral bodies to compensate for the imbalance. According to Kebaish et al. [17], the prevalence of degenerative scoliosis increases linearly from the fifth to eighth decade of life and quickly increases in people aged 90 years.

The clinical presentation and radiological characteristics

Pain syndrome dominates in the clinical presentation of degenerative scoliosis in adults. Pain syndrome can have a mechanical or neurogenic cause. According to Winter et al. [55], one of the causes of pain can be muscle fatigue of the spine (along the entire length of the spine and specifically in the convex side of the curve) due to loss of lumbar lordosis. Pain on the concave side of the curve is due to the spondyloarthrosis and disc space degeneration (disc changes, ligament rupture, abnormal bone growths, and others).

If the sagittal gravity line passes in front of S1 vertebra, lumbar musculature is involved to maintain vertical position. The fact that severity of back pain increases in a linear fashion with grade of positive sagittal imbalance is confirmed by the findings of Glassman et al. [12] in a retrospective review of 752 patients with adult scoliosis.

Neurogenic pain is mainly a characteristic sign of patients with *de novo* scoliosis. Although, patients with idiopathic scoliosis of adults may also suffer from neurogenic pain. Symptoms, including neurogenic claudication and radiculopathy are caused by stenosis in the central spinal canal, lateral recess stenosis or foraminal stenosis.

Liu et al. [27] reported symptoms of nerve root compression associated with degenerative scoliosis. The L3 and L4 roots were commonly compressed by foraminal stenosis or extraforaminal stenosis on the concave side of the curve, whereas L5 and S1 roots were more often affected by lateral recess stenosis on the convex side of deformity (on the concave side of the lower portion of the curve). The Cobb angle and lateral spondylolisthesis were more significant in cases when L3 and L4 root was affected than in cases when L5 and S1 root was compressed [15, 27, 46].

Ploumis et al. [34] reported about 78 patients with *de novo* degenerative scoliosis who underwent conventional radiography and MRI. The authors found that presence of laterospondylolisthesis did not correlate with the volume of the dural sac at this level. Anterior spondylolisthesis was inversely related to the spinal canal size. With increasing the Cobb angle the foraminal area increased on the convex side of the deformity, but did not decrease on the concave side. The researchers stated that ligamentum flavum hypertrophy, posterior disc bulging, and abnormal bony growths are more likely to contribute to appearance of stenosis than scoliosis does.

Laterospondylolisthesis correlates with back pain during idiopathic scoliosis and is largely associated with an increase in curve magnitude during aging [49]. Curve magnitude is commonly significantly lower in patients with *de novo* scoliosis than in patients with adult idiopathic scoliosis. Large magnitudes of lateral spondylolistheses were also observed in patients with adult idiopathic scoliosis.

Perennou et al. [33] showed that radicular pain correlates with degenerative laterospondylolisthesis. Velis and Thorne [51] and Kostuik et al. [21] described laterospondylolisthesis, particularly at L3–L4 and L4–L5 levels as an important predicting factor for the development of back pain and curve increase after reaching skeletal maturity. Scwab et al. [45] by correlating radiographic parameters with VAS scale scores in adult patients with scoliotic deformity found that endplate obliquity angles of L3 and/or L4 vertebrae in the frontal view, lateral rotatory spondylolisthesis, magnitude of lumbar lordosis and thoracolumbar kyphosis correlated with pain. Curve magnitude and the number of levels involved in the curvature are also associated with pain severity. According to Ploumis et al. [34], segmental instability is the source of pain and common causes for the progression of all types of scoliosis adults.

Biomechanics

Humans evolved specific vertebral-pelvic relationships so that to be able to stand and walk upright. Sagittal balance depends on the delicate balance between spinal curves, pelvis shape and position of the lower extremities [37].

Dubousset [11] is the author of a concept of optimal posture and standing balance. He described the "cone of economy" relating to a narrow range within which the body can remain balanced without external support and using minimal effort (Fig. 1).

As the trunk of a standing individual is positioned closer to the periphery of the "cone" (projected from a circle around the feet upward/outward), increasing effort is required to maintain balance. If the trunk extends beyond the cone an individual will fall unless supported with cane, crutch, or others. It has been suggested that spinal imbalance requires markedly elevated energy in an attempt to maintain balance, leading to fatigue and pain [36].

Lafage et al. in a study in [24] confirmed the concept of Dubousset that the standing individual maintains a center of mass within a narrow range in relation to the feet, in all standing subjects despite increased thoracic kyphosis and flattening of lumbar lordosis in patients with age. To maintain a stable center of gravity with the age, compensatory mechanisms are upregulated in humans. Initial compensation occurs through increased lumbar lordosis, if the force of muscles is sufficient and if the lumbar spine remains mobile. Further compensation involves pelvic retroversion. When the extension of the hips reaches its threshold, pelvic tilt can be increased with bent knees [25].

The central sacral line is used in the assessment of the front balance. This line bisects a line connecting the top of the iliac crests and rises perpendicularly. The vertebrae bisected by central sacral line are termed stable vertebrae.

A plumbline offset from the center of C7 vertebra is a main parameter in the calculation of sagittal balance and is commonly termed as the sagittal vertical axis (SVA). Normal sagittal balance in adults by radiographic plumbline falls within a narrow range from the pelvis. Jackson and McManus [13] have measured a value of sagittal vertical axis offset from C7 plumbline and the postero-superior corner of S1 in asymptomatic adults. The value was found to be 0.5 cm (±2.5 cm). In addition, it is well demonstrated that SVA increases with age and leads to sagittal plane anterior imbalance.

In 1998, the first sagittal pelvic modifiers were proposed [26]: pelvic tilt (PT), sacral slope (SS) and pelvic incidence (PI).

PI is defined as the angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the femoral heads axis (the pelvic incidence is an anatomic parameter and is not changed in adults, i.e. its value remains constant, regardless of age and body position; Fig. 2).

SS is the angle between the horizontal and the upper sacral plate (Fig. 3).

PT is defined by the angle between the vertical and the line through the midpoint of the upper sacral plate to femoral heads axis. In the case of abnormal contours of the right and left femoral heads, the midpoint of the bicoxofemoral axis is the center of femoral heads joining the centers of both femoral heads. It is commonly reported as a compensatory mechanism to reduce the body tilt forward by rotation of the pelvis around the hips for the subject to maintain an economic posture – bring the spine over the pelvis (Fig. 4).

After Duval-Beaupere [26], many researchers [14, 22, 27–29, 37, 44, 52] emphasized the importance of pelvic morphology in postural balance in healthy adults and children, in particular through its influence on lumbar lordosis.

Diagnostics

The standard examination of patients usually begins with radiographic examination including the hip joints. Furthermore, frontal-lateral functional imaging, including flexion and extension lateral imaging is performed to identify instability and lateral bending films in frontal view are taken to assess the rigidity of the curves.

MRI is used to determine the grade of stenosis that provides visualization of soft tissues contributing to the shape of the spinal canal, lateral recesses and foramen.

Multi-slice helical CT is useful when planning surgery to determine substantial amounts of stenosis bone structure resection. In the case of contraindication to perform MRI (cardiac stimulator, claustrophobia and other reasons), CT with myelography is performed to assess the localization and degree of stenosis. In patients with scoliosis, multi-slice helical CT with myelography can be more informative than MRI due to the visualization and greater contour contrasting of the dural sac and nerve root cuffs and their relationship with bone structures in complex images.

Conservative therapy

Conservative therapy is the first stage in the treatment of adult patients with spinal deformities. Non-steroidal anti-inflammatory drugs and

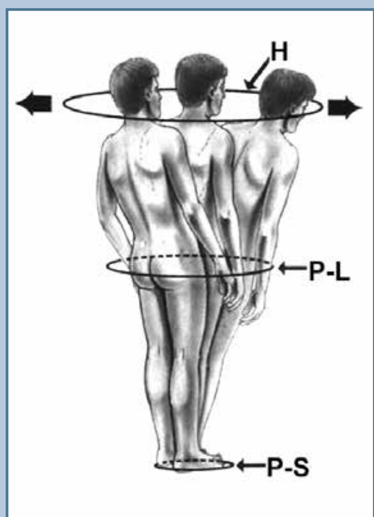

Fig. 1
Dubousset's cone of economy [11]

nonnarcotic analgetics are prescribed. Additionally, various options of braces are used to unload the spine. In the case of aggravation and significant pain syndrome, it is possible to use glucocorticoids. Tricyclic antidepressants and anti-convulsants are commonly prescribed to patients with chronic pain syndrome. Conservative therapy also includes paravertebral and epidural blockade using steroid drugs. Epidural corticosteroid injections provide short-term or long-term relief of symptoms and are mostly effective in radicular pain and in back pain with confirmed spinal stenosis. Frequency of using epidural blockades remains a debatable issue. A recent randomized prospective study assessing the effectiveness of epidural injection of hormones versus intramuscular administration of hormonal preparations and an anesthetic to patients with lumbar spinal stenosis has showed that in the long term, the route of administration does not affect the number of patients who later required surgery. Meanwhile, epidural injections are more effective for pain reduction in the short term [54]. Strengthening of abdominal and spine muscles combined with swimming is also considered an effective way to reduce pain [20, 32, 48, 50].

It is shown that moderate or significant clinical improvement can be achieved within 3-year follow-up in patients with clinical and radiologic spinal stenosis [48].

The indication for surgical treatment of degenerative scoliosis is ineffective conservative treatment. The decision on the range of surgical intervention is a complex issue and for the decision it is highly important to take into account the total degenerative changes of the spine. To facilitate this task, different classifications of spinal deformities in adults have been used in recent times.

Classification and surgical treatment

The surgical treatment decision is always made individually. Surgical treatment is commonly indicated in the case of neurogenic or mechanical pain and lack of effect from conservative treatment. Pathomorphological substrates of pain syndrome can include a frontal and/or sagittal plane imbalance, instability in a spinal motion segment at one or more levels, spondylolisthesis [3, 7].

The clinical significance of radiologic indicators in degenerative scoliosis emphasizes the need for a comprehensive classification system for spinal deformities in adults, which could provide unambiguous characterization of the clinical presentation, the basis for comparing different methods of treatment and choice of the correct option.

Simmons [47] was one of the first to attempt to classify degenerative scoliosis based on radiographic parameters and separated scoliosis into two types:

I – degenerative scoliosis with no or minimal rotatory deformity;

II – degenerative scoliosis involving a significant rotatory component of deformity and decreased lumbar lordosis.

In 2005, Aebi [7] proposed to classify adult scoliosis into three main types depending on the etiology of the deformity:

I – primary degenerative scoliosis caused by asymmetric degenerative changes in the intervertebral disc and facet joints;

II – idiopathic scoliosis, which progresses at elder age;

III – secondary scoliosis of adults;

Fig. 2
The measurement of the pelvic incidence (PI)

Fig. 3
The measurement of the sacral slope (SS)

Fig. 4
The measurement of the pelvic tilt (PT)

IIIa – secondary deformity caused by a variety of vertebral anomalies or pelvic obliquity;

IIIb – secondary scoliosis caused by metabolic diseases (mostly, due to osteoporosis) together with asymmetric disease of the joints and/or vertebral fractures.

Aebi selects the types of deformities based on their causes. However, this classification does not help to choose the treatment option as it does not take into account the quantitative characteristics of the deformity.

In 2007, Ploumis et al. [34] introduced a new classification system for degenerative scoliosis based on the review of the current literature and personal experience. The classification is based on radiologic parameters with clinical modifiers: type I – curves with minimal or no rotation; type II – curves have intersegmental rotation and lateral spondylolisthesis; type III – frontal (>4 cm) and/or sagittal (>2 cm) imbalance. The clinical modifiers include the following: a) back pain without leg pain; b) pain in the innervation area of the sciatic nerve with back pain or without; c) pain in the innervation area of the femoral nerve with pain or without.

Shwab et al. [41, 42, 43, 45] proposed a series of classifications, the drawback of which was absence of pelvic parameter modifier. Lafage et al. [23] to continue the works of French authors have shown a fundamental role of the pelvis as the main regulator of the relationships between the spine and the lower extremities and formation of sagittal balance. It was shown that such spinopelvic parameters as SVA, PT, and the ratio between PI and lumbar lordosis (LL) expressed as PI-LL correlate with pain intensity and disability. These parameters were used to establish the threshold correction values [38] during reconstructive operations. Hence, in 2012 Schwab in cooperation with the Scoliosis Research Society developed a new classification, taking into account these parameters.

In the classification, the curve type describes the coronal aspect of the deformity. The sagittal components of the deformity are characterized by three modifiers. The curve type is determined based on the maximum coronal angle measured according to the standard Cobb angle assessment.

The T type of curve: thoracic major curve is more than 30° (the apical vertebra is T9 or higher).

The L type of curve: patients with lumbar or thoracolumbar major curves are more than 30° (the apical vertebra T10 or lower).

Curve type D: there is a double major curve and each curve is more than 30°.

Curve type N (Normal): there is no major coronal deformity, the curves are not more than 30°.

The first sagittal modifier takes into account two radiographic parameters: PI and LL. PI-LL modifier is the difference between the PI angle and the LL angle, i.e., the proportional relation between PI and LL. This measurement is important for surgical planning in patients with small LL and allows taking into account the necessary post-operative angle LL formed by osteotomy or osteotomies to achieve a harmonious alignment (sagittal balance). The LL is the Gobb angle measured between the superior endplate of L1 and the superior endplate of S1.

The patients are classified according to the PI-LL modifier as follows: "0" with the PI-LL value within 10°, "+" the PI-LL value within 10 and 20°, and "++" the PI-LL value is more than 20°.

PT is an important parameter in the assessment of spinal deformity as the high PT (increased pelvic retroversion) is a compensatory mechanism which can affect and reduce sagittal misalignment. The pelvic tilt modifier assesses the degree of pelvic retroversion.

Based on the PT modifier, patients with PT of less than 20° are classified to "0", within 20 and 30° to "+", and more than 30° to "++" PT modifier.

Global alignment modifier (global balance) is assessed using radiographic indicators of SVA.

According to the SVA modifier, patients with SVA of less than 40 mm are classified as "0", within 40 to 95 mm as "+", and more than 95 mm as "++".

In 2013, Berjano and Lamartina [9] proposed a classification of lumbar deformities in adults, the purpose of which was to assist in choosing the surgical strategy when performing XLIF. This classification includes clinical, radiographic parameters, sagittal balance parameters and involves a given kind of surgical intervention depending on the combination of these parameters (Tables 1, 2).

An in-depth understanding of the vertebral-pelvic relationships is important in the surgical treatment of adult patients with spine deformities. Thorough radiological examination of patients with degenerative scoliosis and assessment of sagittal balance, which has significant value in spinal deformities in adults, as shown in various studies, are required [4, 12, 18, 45].

Poor integration of spinopelvic relationships can lead to an unsatisfactory outcome of surgery and iatrogenic pathology (fixed sagittal imbalance).

At present, several most often used techniques with different modifications have been proposed to restore sagittal balance. These techniques finally are directed at restoration of the lumbar lordosis.

The Smith-Petersen osteotomy is performed in patients with small or moderate sagittal imbalance who require correction of no more than 10° (at the level of osteotomy). Successful correction requires no anterior fusion at the level of osteotomy and adequate correction requires adequate disc height to provide mobility (correction is at the level of the disc) [34].

Osteotomy with wedge-shaped resection of vertebral body, vertebral pedicles and arch is performed at significant sagittal imbalance when the required correction exceeds 30°. Correction is performed at the level of the vertebral body, not at the level of the disc [34].

Resection of vertebral canal is performed during severe sagittal imbalance when the required correction exceeds 45° [7].

Thus, with the majority of classification of degenerative scoliosis, there is still no one generally accepted and routinely applied in practice. In each specific case, the surgeon decides on the range of surgical treatment based on clinical symptoms, affects the main photomorphlogical substrate of the symptoms. Given the interest in degenerative scoliosis, we cannot miss noting of rapidly progressive understanding of this matter that allows hoping for improvement of surgical treatment outcomes of patients.

Thus, surgical intervention can positively influence the quality of life of patients with degenerative scoliosis when conservative treatment methods prove ineffective [2]. The optimal surgical approach depends on the careful evaluation of clinical symptoms and its pathological substrate with necessary taking into account the parameters of global spinopelvic balance.

Positive sagittal imbalance is associated with significant worsening of quality of life and requires surgical intervention. Given that this field of spinal surgery is a relatively novel area, the lack of unified classification principles and approaches for surgical treatment, it is important to study further spinal deformity in adults.

Table 1
Criteria to classify adult scoliosis regarding type of lateral access fusion strategy [9]

Type of deformity	Criteria	Surgical strategy
I: Type I: localized nerve compression in adult scoliosis	Spinal stenosis at 1–2 levels; and two discs remaining between the upper level to be included in decompression/fusion and the apex of the curve; and no severe degeneration or instability (including laterolisthesis) in the disc over the level to be decompressed or fused; and sagittally balanced	Selective decompression or selective decompression and fusion if instability is present or surgery will create instability
II: limited disc disease within the curve	Painful discs within the curve (i.e., Modic I changes in some of the discs, laterolisthesis at one or two discs, vacuum phenomenon in discs with severe collapse) and sagittally balanced (LL > PI); and coronal imbalance <4 cm; and nonprogressive curve and less severe curve (<30°); ideally, painful discs around (over and below) the apex of the lumbar curve	Selective fusion with partial correction (do not correct over adjacent curve correction in bending films to avoid decompensation); consider anterior XLIF alone (when little or no correction is needed) or XLIF and posterior instrumentation to improve and maintain correction, to improve sagittal balance or to restore coronal balance after anterior procedure
III: severe coronal deformity	Pain all over the curve or progressive curve or more severe curve (>30°) or coronal deformity with moderate sagittal imbalance or sagittally compensated	Fusion of the entire curve (as dictated by coronal and sagittal plane deformity): XLIF at all levels or at the more rigid segment plus posterior instrumentation; eventually posterior correction of coronal imbalance if present after XLIF; If discs in the extremes of the curve are preserved and mobile in lateral bending, consider XLIF at the apex (2 discs if apex is a vertebra, 3 discs if apex is a disc) with derotation of the apex through posterior instrumentation and compression in the convexity
IV: sagittal imbalance	No or minor coronal deformity, sagittally imbalanced or sagittally compensated with severe back pain or sagittally compensated with stenosis	Posterior instrumentation and fusion with osteotomies as needed. Consider adding XLIF (same day or staged) to increase stiffness around pedicle subtraction osteotomy or maintain stability in open discs after vertebrotomy; in case of severe sagittal deformity with coronal deformity, consider XLIF at all levels or at the more rigid segments and at the levels of planned posterior osteotomy plus posterior instrumentation and fusion with osteotomies as needed; in selected cases requiring less than 30° of sagittal correction, consider XLIF complete release and lengthening the anterior column with hyperlordotic cage followed by posterior instrumentation (currently under evaluation)

Table 2

Sagittal balance status classification [9]

Status	Parameters of global sagittal spinal balance	Situation of compensatory mechanisms to regain sagittal balance
Sagittally balanced	Sagittal vertical axis passing through center of C7 body is within 5 cm anterior from the posterior margin of the S1 endplate	Pelvic tilt is less than 1/3 of the pelvic incidence, femoral shaft axis is vertical
Sagittally compensated	Sagittal vertical axis passing through center of C7 body is within 5 cm anterior from the posterior margin of the S1 endplate	Increased pelvic tilt (pelvic tilt is more than 1/3 of pelvic incidence) or femoral shaft axis is not vertical (indicating compensatory knee flexion to increase pelvic tilt or translate center of mass)
Sagittally imbalanced (decompensation)	Sagittal vertical axis passing through the center of the C7 body is more than 5 cm anterior from the posterior margin of the S1 endplate	–

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Received 07.06.2016
Review completed 23.06. 2016
Passed for printing 01.07.2016

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