North American Spine Society Journal (NASSJ) 19 (2024) 100531

Contents lists available at ScienceDirect

North American Spine Society Journal (NASSJ)

journal homepage: www.elsevier.com/locate/xnsj

Spinal Alignment/Deformity

Spinal alignment and surgical correction in the aging spine and osteoporotic patient

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ARTICLE INFO

Keywords:
Osteoporosis
Adult Spinal Deformity Frailty Index (ASD-FI)
Adult spinal deformity
Spinal alignment
Body mass index (BMI)
Global Alignment and Proportion (GAP) score
Scoliosis Research Society-Schwab Adult Deformity Classification

ABSTRACT

Background: The aging spine often presents multifaceted surgical challenges for the surgeon because it can directly and indirectly impact a patient's spinal alignment and quality of life. Elderly and osteoporotic patients are predisposed to progressive spinal deformities and potential neurologic compromise and surgical management can be difficult because these patients often present with greater frailty.
Methods: This was a literature review of spinal alignment changes, preoperative considerations, and spinal alignment considerations for surgical strategies.
Results: Many factors impact spinal alignment as we age including lumbar lordosis flexibility, hip flexion, deformity, and osteoporosis. Preoperative considerations are required to assess the patient's overall health, bone mineral density, and osteoporosis medications. Careful radiographic assessment of the spinopelvic parameters using various classification/scoring systems provide the surgeon with goals for surgical treatment. An individualized surgical strategy can be planned for the patient including extent of surgery, surgical approach, extent of the constructs, fixation techniques, vertebral augmentation, ligamentous augmentation, and staging surgery.
Conclusions: Surgical treatment should only be considered after a thorough assessment of the patient's health, deformity, bone quality and corresponding age matched alignment goals. An individualized treatment approach is often required to tackle the deformity and minimize the risk of hardware related complications and pseudarthrosis. Anabolic agents offer a promising benefit in this patient population by directly addressing and improving their bone quality and mineral density preoperatively and postoperatively.

Introduction

The aging population presents complex surgical challenges that directly and indirectly impact spinal alignment. Spinal degeneration is a natural process that can occur at any vertebrae. In a general adult spinal deformity population, the impact on health, disability, and general quality of life has been reported for sagittal plane deformity but little has been described for coronal and multiaxial deformities [1–4]. The impact of aging can have a direct impact on what would be considered normative spinal alignment parameters [5].

In the United States, there are over 10.3 million people with osteoporosis and 43.4 million diagnosed with low bone density with these numbers expected to increase by 32% in the next 10 years as our population ages [6]. Osteoporosis specifically can result in fracture and subsequent deformity and alignment issues as it predisposes patients to progressive spinal deformities and potential neurologic compromise [7].

Surgical management in this population can present a myriad of challenges for spinal alignment because older and osteoporotic patients often present with greater frailty [8]. Surgery in this population has a higher complication rate that may be mitigated by a variety of

FDA device/drug status: Not applicable.

Author disclosures: ***USM:*** Nothing to disclose. ***WJL:*** Nothing to disclose. ***KL:*** Nothing to disclose. ***RH:*** Grants: Medtronic (C), National Institute of Health (D), Scholiosis Research Society (C) All monies paid to institution. ***WFL:*** Stock Ownership: 4-Web <1%; Expanding Innovations <1%; Consulting: 4-Web (0), DePuy (0). Speaking and/or Teaching Arrangements: 4-Web (0). Scientific Advisory Board/Other Office: Innovasis (0), TruSpine (0), Vertiflex (0). Grants: Abryx (C); Cerapedics (E); DePuy (E); Empirical Spine (E); Medtronic (E); Spinal Kinetics, Inc. (E); 3 Spine (F) All monies paid to institution.

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https://doi.org/10.1016/j.xnsj.2024.100531
Received 3 July 2024; Received in revised form 19 July 2024; Accepted 22 July 2024
Available online 30 July 2024
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preventative optimization strategies for bone quality and general health. Surgical strategies are still a source of debate. Alternative anchor types, level selections and strategies may be beneficial. Additionally, staged surgical management may be beneficial in this evolving and rapidly increasing area of spinal deformity surgery as our population ages.

Spinal alignment changes

As we age, many factors impact not only our standing spinal alignment but also impact our ability to sit and stand [9]. When comparing the relative ratio of mobility of the spine to the femoral acetabular joint, aging results in greater stiffness in the spine as compared to the hip when measured during transitioning from sitting to standing. Lumbar lordosis flexibility decreases 4.5° per decade while hip flexion decreases 3.6° per decade. This has been seen to a greater extent in male patients. The hip user index is the percentage that quantifies sagittal femoroacetabular flexion (ΔPFA) relative to overall sagittal flexion arc (SFA) when moving from the standing to the deep-seated position: Hip User Index = ΔPFA/SFA X 100%.

A high hip user index means that the hip contributes more to sagittal movement, while a low hip user index means that the movement takes place primarily in the lumbar spine [9]. The hip user index has been reported as statistically significantly increasing from 63.2 to 68 in patients over the age of 60 illustrating the relative stiffness of the lumbar spine as compared to the hip joint.

This unique relationship has been further illustrated by Mills et al who showed that patients with severe hip OA at the time of primary lumbar fusion had a significantly increased risk of spinal reoperation at 3 and 5 years postoperatively [10]. There has been a classic contention that surgeons should address the hip before the spine. The relationship between the lumbar spine and hip is compensatory. During the transition between standing and sitting, the pelvis retroverts to allow for femoral flexion, and then the lumbar spine flexes to maintain upright posture. Loss of motion in the lumbar spine demands more hip motion and a stiffer hip demands more lumbar spinal motion [10]. When both areas are pathologic, their interaction is difficult to separate.

Deformity can further complicate this issue. Sultan et al. found that patients with concurrent adult spinal deformity and total hip arthroplasty are at increased risk of hip dislocations and revisions with a compiled 2.9% dislocation rate in 1,167 patients [11]. Patients who underwent adult spinal deformity correction demonstrated reduced relative acetabular anteversion and tilt (mean, -7° ± 10°, $p < .001$). This study found that arthroplasty patients with concurrent lumbosacral fusion had dislocation rates ranging between 3% at 1 year and 7.5% at 2 years compared to 0.4%–2.1% dislocation rates in matching cohorts ($p < .001$) [11]. This suggests the need for a more careful consideration of lumbar and pelvic alignment for the adult deformity patient.

Consideration can and should be made in the aged patient with concomitant hip arthritis to address the overall lumbar and pelvic alignment before positioning an acetabular prosthesis, and also for the use of dual-mobility articulations in such patients. Dhawan et al. reported on 227 patients undergoing primary total hip arthroplasties with adverse spine or pelvic mobility parameters including severe spinal deformity and found an overall survival of 99.1% at 14 months with no reported dislocations with the use of dual-mobility articulations [12].

In addition to the spinal stiffness and deformity imparted by age related degeneration, aging can also result in osteoporosis and osteoporotic fractures. Focal or cumulative fractures can result in thoracic hyperkyphosis and/or worsening of preexisting scoliotic deformities. Osteoporotic fractures with or without superimposing morphological changes may also result in secondary scoliotic deformities.

Plais et al. found that lumbar fractures and/or multiple fractures at the lumbar or thoracolumbar regions are risk factors for sagittal malalignment in patients over the age of 70 [13]. They retrospectively studied 249 osteoporotic patients and categorically found a greater percentage of lumbar fractures in the sagittal malalignment cohort as compared to normal alignment cohort (34% vs. 11%; $p < .001$). A similar distribution was not seen for thoracic fractures (9% vs. 34%). Patients with 3 or more lumbar or thoracolumbar fractures had an increased risk of sagittal malalignment, defined as one of the following parameters: PI-LL > 8.3°, LL-TK < 2.1°, SVA > 65.8 mm [13].

Treatment planning for deformities in aging and osteoporotic patients should involve a multidisciplinary approach focusing on various factors that affect overall treatment outcomes. These treatment considerations are discussed elsewhere in the paper.

Preoperative considerations

Osteoporosis is often characterized by muscular weakness, poor balance control, and postural deformities. Patients with osteoporosis have been documented to have impaired balance performance, although they may not experience "classical motor control" problems that accompany central nervous system disorders. Women with osteoporosis have reduced flexibility and mobility that affects their walking and contributes to a greater risk of falling than men. In the early stages of bone loss, symptoms may not present themselves; however, once osteoporosis has weakened the bones, symptoms may include back pain, loss of height, stooped posture, and a bone that breaks more easily. This condition can lead to fracturing of bones and can cause mobility issues in the spine as a result of pain, structural changes, and a curved posture.

The pain associated with osteoporosis can restrict mobility and result in postural deformities like kyphosis. Fractures in particular such as compression fractures or osteoporotic burst fractures, can suddenly and catastrophically limit mobility and cause pain. The most dangerous contributor to broken bones among older populations is falling in or out of the home. Osteoporosis weakens bones and allows serious injuries to occur even with a small fall.

Preoperative assessments

Preoperative assessment of overall patient's health is of utmost importance. As per Xue et al., frailty is essentially an age-related decline in a multisystem physiological response to everyday stressors to acute major stressors such as major surgery [14]. Frailty assessment can be carried out using various validated tools. Charleson Comorbidity index and Adult Spinal Deformity Frailty Index (ASD-FI) are 2 commonly used preoperative assessments. ASD-FI, designed by Miller et al. [15], has been shown to have positive correlation with higher risk of major postoperative complication such as wound infections, proximal junctional failure, pseaudarthrosis reoperations, and mortality.

Assessment of nutritional status is equally important. Serum albumin level is widely used to determine overall nutritional status of the patients. Serum albumin values below 3.5 gm/dL is considered a standardized marker for malnutrition. Low serum albumin levels/poor nutritional status is associated with increased 30-day mortality risk, risk of postoperative wound complications, risk of pulmonary and thromboembolic complications [16,17]. Thorough assessment of cardiovascular and pulmonary function is commonly done as a part of preoperative assessment.

Preoperative assessment of bone health and optimization

Management of spinal deformities in elderly population presents a different set of challenges due to the presence of metabolic bone disease. Osteoporosis is the most important modifiable risk factor that has been shown to increase the risk of postoperative hardware related complications, risk of proximal junctional failure or proximal junctional kyphosis and pseudarthrosis [3,18,19]. When these complications occur, revision surgery is oftentimes needed. This leads to a cascading effect of both age and bone quality, worsening patient outcome and can lead to permanent pain and disability.

A bone mineral density (BMD) assessment can predict mechanical complications of spine surgery especially proximal junctional failure [20]. Preoperative assessment of bone quality is an important step in surgical planning. BMD has been used in combination with body mass index (BMI) and Global Alignment and Proportion (GAP) score to predict risk of postoperative complications. BMD assessment is traditionally carried out using dual energy X-ray absorptiometry (DEXA) scan. Spine-based DEXA scans can be inaccurate due to sclerotic bone and osteophytes secondary to spondylotic changes in the spine. A combination of hip and wrist X-ray is considered optimal determination of BMD.

CT-based estimation of bone density has essentially replaced DEXA scans in assessing bone mineral density. The average Hounsefield unit measurement in the mid-lumbar spine is routinely used as an accurate measurement of bone density. An average Hounsefield unit value of less than 105 has been shown to correlate well with osteoporosis. Higher Hounsfield unit measurements (>159) [21] at upper instrumented vertebra (UIV) and UIV+1 has been shown to protect against PJK/PJF while low Hounsefield measurements (<105) at these levels has been shown to increase the risk of PJK and PJF [22].

Osteoporosis medications

Patients with osteoporosis require a thorough investigation of various bone metabolism parameters. There are currently a variety of medication treatments that are used for osteoporosis to increase BMD, such as antiresorptives, denosumab and anabolic drugs, like teriparatide. Several studies have reported that combining teriparatide and denosumab improves spinal BMD in the osteoporotic patient [23–26]. These studies also found that if denosumab was not administered in combination with teriparatide, patients showed a significant decline in BMD and were at higher risk for fragility or vertebral fractures [23,25].

Fatima et al. [27] conducted a review and meta-analysis of 771 patients from 12 studies to assess the efficacy of teriparatide on lumbar fusion surgery outcomes. Lumbar fusion rates were significantly higher in patients who received teriparatide. Additionally, patients using teriparatide had significantly reduced subsequent vertebral fractures and sagittal malalignment and had 30% less likelihood of screw loosening. The authors concluded that teriparatide resulted in higher fusion rates [27].

Preoperative treatment with anabolic medications such as teriparatide has shown to improve the bone quality and increase the pedicle screw pull out strength and decrease the incidence of hardware failure and proximal junctional failure and vertebral fractures [19]. Ueno et al. [28] reported on the use of parathyroid hormone administration 1 to 2 weeks preoperatively and continued at least 6 months postoperatively for balloon kyphoplasty. They found the parathyroid hormone group had significantly lower vertebral body fractures compared to the nonuser group and parathyroid hormone may reduce the risk of vertebral body fractures [28].

Although the evidence on this is equivocal, teriparatide and other anabolic medications are now routinely used preoperatively for a period of at least 3 months prior to surgery and are continued during postoperative period for a minimum of 6 months to minimize the risk of hardware failure and vertebral fractures [29]. Kim et al. [30] concluded that long-term postoperative treatment of teriparatide after lumbar fusion surgery resulted in higher fusion rates versus shorter postoperative treatments. Maruo et al. [31] found that pre and postoperative teriparatide treatment increased the Hounsfield unit at UIV + 1 by 20.8% concluding that more prolonged preoperative treatment improves bone quality and may prevent osteoporosis complications. Currently, there is no definitive consensus regarding the duration of preoperative and postoperative teriparatide treatment [27].

Spinal alignment considerations

Overall spinal alignment for adult spinal deformity should be carefully evaluated especially in patients who are older and patients with osteoporosis. Careful radiographic assessment predominantly of the sagittal plane spinopelvic parameters not only allows the surgeon to understand the magnitude of the deformity but also provides goals for surgical treatment and alignment goals. The alignment goals should be modified based on the patient's age. This section elaborates on various classification/scoring systems that aid in understanding the evaluation of the deformity and planning for surgical correction.

The Scoliosis Research Society-Schwab Adult deformity classification system has been widely used for classifying the adult spinal deformities and to quantify magnitude of sagittal plane malalignment in these patients [32]. Patients are classified into 4 coronal groups based on their primary major curve type: Thoracic only (lumbar curve < 30°), TL/Lumbar only (thoracic curve < 30°), double major with both T and TL/L curve > 30°, and no major coronal deformity (all curves < 30°). Sagittal plane modifiers are designed based on spinopelvic parameters and overall global alignment. The modifiers include pelvic incidence (PI), lumbar lordosis (LL), global alignment based overall sagittal vertical axis (SVA) magnitude and pelvic tilt (PT). Each sagittal modifier is graded from 0, + and ++ based upon the magnitude of measurement of each modifier (Table 1).

However, these linear values of sagittal plane modifiers have been less useful in patients with lower normal or upper normal values of pelvic incidence. Individuals with high pelvic incidence tend to have higher sacral slope and higher pelvic tilt values. Essentially, in these patients, pelvic tilt values in excess of 20° could be a normal anatomical finding although considered abnormal when Schwab's sagittal plane modifier is considered. Aiming for a PT value of less than 20° may be disabling for these patients. Magnitude of lordosis that comes from L4-S1 in comparison to overall LL, the lordosis distribution is equally important as compared to considering the PI-LL values. The SVA target values of <4cm, fails to take into consideration the downside of overcorrection or the negative SVA value. The Schwab scoring applies these criteria for correction of the deformity irrespective of patient's age.

To overcome the shortfalls of the Schwab classification, the Global Alignment and Proportion (GAP) score was devised by Yilgor et al. [33]. GAP scoring provides a continuum of alignment spectrum in proportion to the pelvic incidence. The scoring system considers the overall pelvic version, magnitude and distribution of lumbar lordosis, global spinopelvic alignment and generates a score that determines the alignment disproportion seen as compared to the "ideal" or normative values seen in asymptomatic population. The score also takes into considera-

Table 1
SRS- Schwab classification system.

Coronal Curve Types	Sagittal Modifiers
T (thoracic): Thoracic only with lumbar curve < 30°	Pelvic Incidence (PI) minus Lumbar Lordosis (LL) 0: within 10°
L (lumbar): TL (thoroacolumbar)/lumbar only with thoracic curve < 30°	+: moderate 10°–20°
	++: marked >20°
D (double): Double curve with T and TL/L curves > 30°	Sagittal vertical axis (global alignment)
	0: <4 cm +: 4–9.5 cm
N: No major coronal deformity all coronal curves < 30°	++: >9.5 cm
	Pelvic Tilt (PT) 0: <20° +: 20°–30° ++: >30°

Table 2
Global alignment and proportion (GAP) scores [33].

Parameters	Range	Score	Categories
Relative Pelvic Version (RPV)			
(RPV = Measured – Ideal Sacral Slope)			
Ideal sacral slope = PI x 0.59 + 9			
Severe retroversion	<–15°	3	
Moderate retroversion	–15° to –7°	2	
Aligned	–7° to +5°	0	
Anteversion	>5°	1	Total Score: 0–2
Relative Lumbar Lordosis (RLL)			Proportioned
(RLL = Measured – Ideal Lumbar Lordosis)			
Ideal lumbar lordosis = PI x 0.62 + 29			
Severe hypolordosis	<25°	3	
Moderate hypolordosis	25°–14.1°	2	
Aligned	14°–11°	0	
Hyperlordosis	>11°	3	
Lordosis Distribution Index (LDI)			Total Score: 3–6
LDI = L4-S1 Lordosis/L1-S1 Lordosis x 100)			Mildy Disproportioned
Severe hypolordotic	<40%	2	
Moderate hypolordotic	40%–49%	1	
Aligned	50%–80%	0	
Hyperlordotic	>80%	3	
Relative Spinopelvic Alignment (RSA)			Total Score: ≥7
RSA = Measured – Ideal Global Tilt			Severely Disproportioned
Ideal global tilt = PI x 0.48 - 15			
Severe positive malalignment	>18	3	
Moderate positive malalignment	18–10.1	1	
Aligned	10 to –7	0	
Negative malalignment	<–7	1	
Age Factor			
Elderly adult	≥60 years	1	
Adult	<60 years	0	

tion the age of the patient. The composite score helps in predicting the risk of mechanical complications in patients with adult spinal deformity (Table 2).

The SRS Schwab classification provides a basic framework for defining and assessing adult spinal deformity and provides a rough outline for alignment goals while the GAP scoring aids in predicting risk of mechanical complications and provides proportionate alignment goals for an individual patient in relation to their pelvic incidence. However, these scoring systems fail to provide alignment guidelines that should be followed based on individual patient's age.

Lafage et al. [34] retrospectively reviewed adult deformity patients undergoing operative and nonoperative treatments and stratified the patient population based on their age (<35, 35–44, 45–54, 55–64, 65–74, >74 year olds) consistent with US-normative values of SF-36 physical component score (PCS). Patients were then assessed to find their baseline spinopelvic radiographic parameters (lumbar-pelvic mismatch (PI- LL), pelvic tilt (PT), sagittal vertical axis (SVA), and T1 pelvic angle (TPA)), age, and corresponding PCS using linear regression analysis. Normative values of SF-36 PCS values were then used to determine the age specific alignment targets. The authors concluded that sagittal spinopelvic parameters vary with age and realignment targets should be individualized based on the patient's age. Aggressive targets should be reserved for younger patients and the target values in the elderly patients should be reduced [34].

Lafage et al. [35] then created a sagittal created a Sagittal Age-Adjusted Score (SAAS) using PI-LL, PT and TPA. The score is determined by calculating the magnitude offset of these values in comparison to age-adjusted targets. For scoring, 0 points were given if the parameter was within 10 years of the patient's age matched target (Match). For each 20 years above the age-adjusted target, 1 point was added (e.g., + 1 point between + 10 and + 30, + 2 points between + 30 and + 50). Conversely, 1 point was subtracted for each 20 years below the age-adjusted target (e.g., -1 point between -10 and -30, -2 points between -30 and -50). The composite SAAS was calculated by adding all 3 components. Negative composite score values suggested under correction while a positive value suggested over correction [35] (Fig. 1).

Surgical strategies

After careful evaluation of the patient and their deformity, planning for these complex surgeries requires an individualized approach based on patient's overall health, bone quality and deformity.

Extent of the surgery

For elderly patients or in patients with high frailty, careful consideration should be given to minimizing the extent of surgery. Differentiating between stenosis related claudicatory symptoms versus radicular symptoms that result from 1 -or 2-level concave side foraminal and/or foraminal stenosis is of utmost importance. Selective nerve root blocks/transforaminal epidural steroid injections may help determine the symptomatic level.

Equally important is distinguishing between stenosis symptoms versus deformity-related mechanical back pain symptoms. Every attempt should be made to limit longer deformity surgeries in patients with significant sagittal and coronal imbalance. Advances in minimally invasive surgery (MIS) decompression techniques and spinal endoscopy techniques, optimal decompression can be achieved using either a far lateral approach or midline approach for decompression.

Role of anterior surgery

Anterior surgery in combination with posterior surgery offers several advantages over posterior only surgery. Anterior surgery allows near total discectomy, placement of large diameter spacers with a large surface area which are supported by a stronger peripheral ring apophyseal bone. The optimal placement of the anterior-based spacers also helps in the restoration of disc and foraminal height and offers the ability to indirectly decompress spinal canal. Anterior-based spacers and bone graft placement significantly improves the chances of arthrodesis across the disc spaces.

Anterior surgical techniques may provide powerful segmental sagittal correction when combined with posterior instrumentation. Biologi-

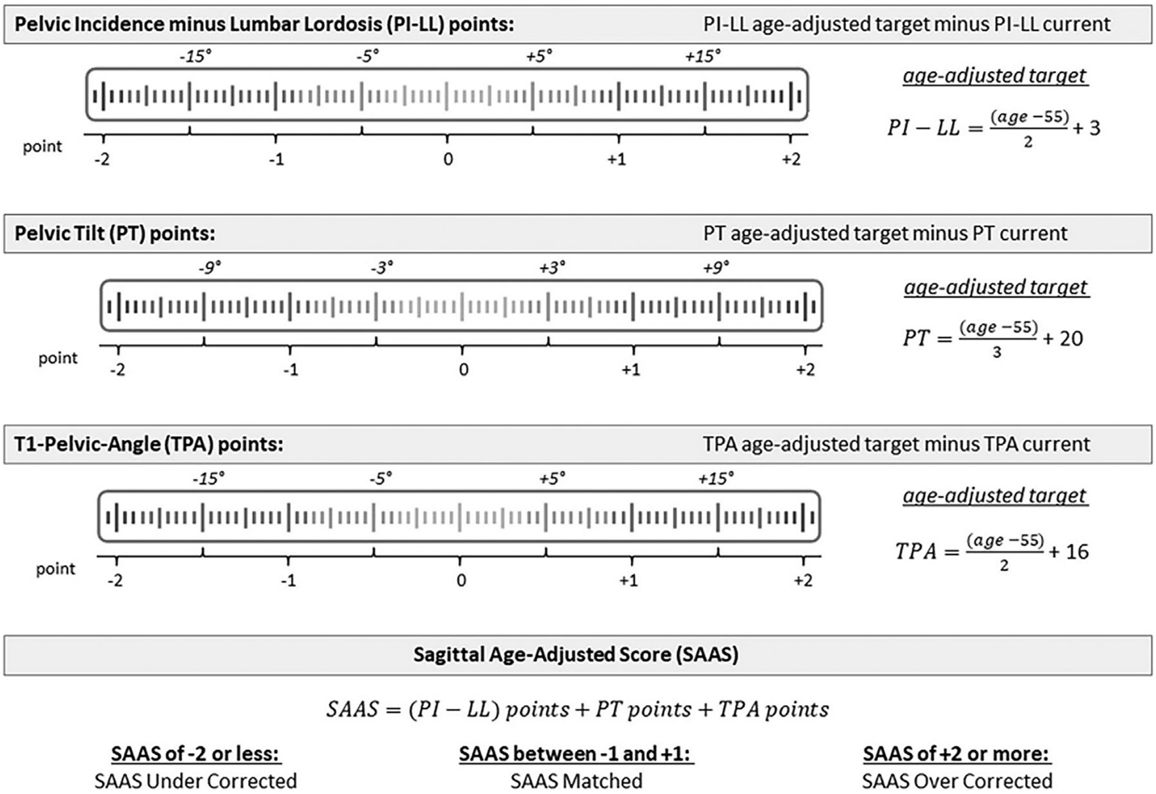

Fig. 1. Illustration of the method of calculation of sagittal age-adjusted score (SAAS) using pelvic incidence, Pelvic Tilt and T1-pelvic angle to evaluate age-related spinal alignment targets [35]. (Used with permission).

cally, the disc space has excellent fusion potential due to the large surface area of the endplates and their rich blood supply. Although historically anterior interbody grafts and cages suffered from issues with subsidence and slippage, newer hyperlordotic cages and improvement in MIS approaches and techniques have largely addressed these previous concerns.

Combined approaches

Combined approaches allow for superior sagittal deformity correction with improved global tilt and global alignment and proportion (GAP) scores compared to posterior only approaches. Despite increased surgical invasiveness of combined approaches, Silva et al. [36] found no difference in immediate complication rates and at 2 year follow-up demonstrated significantly decreased readmission and reoperation rates, and significantly higher HRQoL scores. Combined approaches also demonstrated lower rates of proximal junctional kyphosis and mechanical failure at the UIV including UIV fracture, screw pullout, and spondylolisthesis compared to posterior spinal fusion only. Anterior surgery should be considered in patients who are osteoporotic, have high risk of pseudarthrosis, rigid deformities and curves that are more than 70° [36].

Extent of the construct

In an aging population, especially osteoporotic patients, it is important to carefully plan for proximal and distal fixation points. Distal fixation should be extended to pelvis in all of these patients to minimize the risk of pseudarthrosis at the lumbo-sacral junction, decrease the risk of hardware failure or sacral insufficiency fracture. A majority of these patients also present with thoracic hyperkyphosis due to structural vertebral changes secondary to osteoporosis. In this subset of patients, the construct should be extended to the proximal thoracic spine.

While this can be protective for proximal junctional failure, this strategy can also result in coronal malalignment which is less tolerated when constructs extend higher in the thoracic spine [1]. Due to bone weakness, there is a high pullout rate. Instead of doing long fusion surgeries, it may be optimal to do small, focused surgeries addressing the patient's complaints and expectations. Staged surgery also allows for recovery time in older patients who may not be able to tolerate large amounts of blood loss. Treatment must be individualized based on the cause, disability, and patient expectation.

Fixation techniques

Bone quality plays a crucial role in instrumented fusion, and preoperative planning should include careful consideration of the bone quality at the planned UIV and UIV + 1. In osteoporotic patients, decreased bone mineral density (BMD) whether measured via DEXA scan or CT-based BMD at the UIV and UIV +1 is associated with increased risk of PJK and PJF [22,37].

Posterior semi-rigid junctional fixation techniques seek to address these risks and provide a gradual transition zone or "soft landing" from the construct to the proximal vertebral levels. A variety of these techniques have been investigated to address this risk including semi-rigid anchors such as transverse process hooks, sublaminar hooks tape, interspinous mesh, and unilateral instrumentation at the UIV and noninstrumented fusion of the UIV + 1.

Vertebral augmentation

Osteoporotic adult spinal deformity patients are at increased risk of developing proximal junctional kyphosis (PJK) due to a lack of anterior vertebral body resistance to compression which can lead to vertebral body collapse and progressive kyphosis as well as an increased risk of proximal pedicle screw failure due to decreased pull out strength. Given these risks, the rationale for vertebral body cement augmentation of the UIV and UIV + 1 is convincing.

The primary aim of vertebroplasty at the UIV +1 is to prevent vertebral body collapse and kyphosis whereas cement augmentation at the UIV or other levels within the construct via fenestrated pedicle screws is to reinforce the bone screw interface. This technique has demonstrated improved fixation with decreased pedicle screw failure in numerous biomechanical studies [38,39]. There are inherent risks to this strategy.

While cement augmentation does decrease the risk of pedicle screw pull out and improves the integrity of the vertebra and its resistance to compression and kyphosis, transitioning to noncement augmented vertebrae remains challenging. Additionally, cement augmentation does introduce several potential risks including neurologic injury secondary to extravasation into the spinal canal or neuroforamen as well as the rare but potentially life-threatening risk of cement embolization to other organs such as the heart or lungs.

Ligamentous augmentation

As previously stated, long-segment posterior instrumentation produces stress at the proximal termination which may cause PJK. To reduce these transitional stresses, the use of proximal junctional polyethlene tethers has been studied. A recent clinical review by Sursal et al. [40] on the use of tether from several studies, suggested that the use of tethers for ligamentous augmentation at the proximal junction may reduce the development of PJK/PJK. Due to the stresses at the proximal junction, the authors believe no single technique will resolve this surgical complication. They state additional studies need to be conducted to establish ideal tether configurations, materials, and tether tension [40].

Staged surgeries

The debate between staged versus same-day spine surgery continues as many other surgical procedures trend towards shorter hospital stays and day surgeries. Some surgeons advocate for same-day spine surgery citing minimized costs and shorter hospital stays, while others advocate for staged surgeries citing reduced risk of complications and the ability to assess the adequacy of realignment or indirect decompression between stages via imaging or clinical examination.

A recent meta-analysis [41] reviewing 16 retrospective studies compared staged spinal fusion and same-day surgeries finding no significant difference in estimated blood loss, mortality, reoperation rates and non-home discharges between groups. However, staged surgery was found to be associated with longer operative times, increased length of stay, and higher rates of VTE. There were limitations to this article that may skew its conclusions and generalizability. They did not compare the patient populations regarding patient characteristics, the magnitude of surgery such as the number of levels involved or mentioned the rationale for staged versus same-day surgery. This makes it difficult to compare these approaches in a meaningful way. Future studies addressing these limitations could provide a clearer answer to this controversial question [41].

Conclusions

Treatment of adult spinal deformity in aging and osteoporotic patients presents a unique set of challenges from deformity as well as from a general health perspective. Surgical treatment should only be considered after a thorough assessment of the patient's health, deformity, bone quality and corresponding age matched alignment goals. An individualized treatment approach is often required to tackle the deformity and minimize the risk of hardware related complications and pseudarthrosis.

Skeletal anabolic agents such as teriparatide and denosumab offer a promising benefit in this patient population by directly addressing and improving their bone quality and mineral density preoperatively and postoperatively. Some studies have shown decreased pedicle screw complications and vertebral body fractures; however, the literature is equivocal on its impact on PJK and PJF [42–44].

Declarations of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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