Chapter

Planning Cervical Deformity Surgery Including DJK Prevention Strategies

Themistocles Protopsaltis and Ethan Sissman

Abstract

Distal junctional kyphosis (DJK) is a major concern following cervical deformity (CD) correction, leading to failed realignment and revision surgery. In this chapter, we describe our approach to the treatment of cervical deformity and the steps taken to minimize the risk of DJK post-operatively by tailoring the construction to the individual patient. In this chapter, we describe our approach to the treatment of cervical deformity and the steps taken to minimize the risk of DJK post-operatively by tailoring the construction to the individual patient. First we focus on characterization of the baseline deformity. Secondly, we assess our patients clinically. Thirdly, we simulate the correction with the use of novel in-construct measurements. The fourth step is to develop a DJK prevention strategy tailored to the individual. The last step is to perform surgery and check correction during the operation.

Keywords: cervical deformity, DJK, distal junctional kyphosis, DJK prevention, in-construct measurements, cervical deformity correction

1. Introduction

Recent studies have focused on how sagittal malalignment of the cervical spine influences outcomes and promotes impairment of quality of life. In order to further understand cervical movement, compensatory mechanisms and pathologies, there are basic biomechanical properties parameters that should be considered. These include mass (m), force (F), standard gravity (g), moment arm (L), bending moments (M) and instantaneous axis of rotation (IAR). In the upright position the head creates a gravitational force on the cervical spine with a magnitude, of F = m x g. This gravitational force then creates a forward bending moment, M, around a fulcrum of rotation, also known as the IAR. The magnitude of the bending moment is calculated by M = F x L, in which L is the distance between the IAR and the center of gravity line.

Yogadanan et al. [1–6] showed that for cadaver studies conducted in the last five decades the center of gravity (COG) or center of mass (COM) of the head is located approximately 1.8 cm anterior and 6.0 cm superior to the occipital condyle. The numbers vary from one cadaver study to the next [6–16]. The head to total body mass (TBM) ratio was 7.37% + − 0.6%. The mean head mass was 4.770.3 kg [17].

In a normally aligned lordotic cervical spine, the posterior tension band and paraspinal muscles counteract the forward bending movement created by the weight of the head, maintaining the natural cervical alignment. When cervical kyphotic deformity is present, the head COM moves anteriorly and the moment arm, L, increases relative to the IAR, creating a larger bending moment, M. This results in greater paraspinal muscle contraction to keep the head erect, ultimately followed by exertion and pain.

The weight-bearing features of the cervical spine have been grouped into an anterior column, including the vertebral bodies and intervertebral discs, and two posterior columns, consisting of the facet joints [6]. It has been estimated that the anterior column is responsible for bearing up to 82% of the weight of the head while the posterior column is responsible for up to 33% [18]. By creating a larger bending moment, M, the kyphotic cervical deformity shifts the axial load anteriorly, which probably accelerates cervical disc degeneration. Disc degeneration might cause further cervical kyphosis, leading to an apparent vicious cycle.

Likewise, junctional failures of fusion are clearly the result of an imbalance of anterior column compression forces and posterior column tension band strength [1]. Biomechanical studies investigating the effects of spinal fusion on adjacent levels have shown that adjacent unfused levels compensate for the loss of cervical range of motion (ROM) in fused levels [19]. Maiman et al. [20] described a finite-element model of the cervical spine to investigate the effect of cervical spine fusion on adjacent levels. There was increased flexion-extension rotational movement of the disc in the sagittal plane especially at the upper adjacent level of the fusion. And this may contribute further to the pathologic progress.

Individualized optimization of surgical alignment has been shown to improve outcome regarding PJK [21].

Adult cervical deformity (ACD) of the spine has been shown to have a substantial negative impact on health-related measurements [20]. Therefore surgery to correct ACD can have a profound effect on improving the patient's health status. A common complication following fusion surgery is excessive kyphosis at one end of the fused construct. For example, thoracolumbar deformity correction commonly results in proximal junctional kyphosis (PJK), with reported rates as high as 40% [22]. In ACD surgery, fusions are usually extended to the upper cervical spine, which increases the likelihood of stress at the caudal part of the fusion construct, potentially leading to distal junctional kyphosis (DJK) or failure (DJF). In 2019, Oren et al. [23] introduced the utility of measurements of spinopelvic angles on prone lateral radiographs as predictors of global post-operative alignment in thoraco-lumbar deformity surgery. Similar measures are now in development for cervical deformity correction.

In this chapter, we describe our approach to the treatment of cervical deformity and the steps taken to minimize the risk of DJK post-operatively by tailoring the construction to the individual patient.

First we focus on characterization of the baseline deformity. Secondly, we assess our patients clinically. Thirdly, we simulate the correction with the use of novel in-construct measurements. The fourth step is to develop a DJK prevention strategy tailored to the individual. The last step is to perform surgery and check correction during the operation.

2. Characterization of the deformity

Ames and colleagues [23] have developed a comprehensive system of classification for cervical deformity. It defines the deformity driver and assigns severity points for four cervical parameters, the cSVA, CBVA, TS-CL, and myelopathy.

The classic measure of sagittal alignment in the cervical spine is the **cervical sagittal vertical axis (cSVA)** which measures the distance between a plumb line dropped from the centroid of C2 to the posterior superior aspect of C7. Hardecker et al. defined normative values ranging from 0.5 to 2.5 cm [24]. Several studies, one of them Tang et al. [25] have shown that high post-operative cSVA correlated with poor post-operative outcomes in patients undergoing cervical fusion. A cSVA over 4 cm corresponds to a moderate disability threshold. cSVA correlates with outcome measures in patients with thoracolumbar deformity as well as myelopathy.

The **T1 slope (T1S)** has emerged as an important measurement for pre-operative planning. It is the angle formed by a line drawn along the superior endplate of T1 and a horizontal reference line at the median sagittal cervical vertebra from the CT radiographs. Knott et al. [26] predicted that when the T1 slope is higher than 25 degrees, patients had at least 10 cm of positive sagittal imbalance. Ayres et al. [27] showed that a T1 slope above 30 degrees, indicates the need to perform full-length spine radiographs to identify potential concurrent thoracolumbar (TL) deformity. The right technical conditions with the use of long X-ray cassette radiographs should be met from the beginning, as shown by Ramchandran [28, 29]. In his survey among spine surgeons, 58% opted for longer fusion constructs to the mid- or lower thoracic spine in cervical deformity, when presented with long cassette radiographs. A T1 Slope above 30 degrees was associated with worse sagittal balance and spinopelvic parameters values after corrective surgery [30]. Kim et al. showed that a high T1 slope in myelopathy patients undergoing laminoplasty predicted postoperative kyphotic alignment after laminoplasty [31].

An important marker of cervical deformity is the **C2 slope (C2S)**, which correlates with **T1 Slope Minus Cervical Lordosis (TS-CL)**, one of the Ames parameters of CD. This correlation is explained by the fact that the C2 slope is a mathematical approximation of the TS-CL [32]. However, C2S is simpler and more efficient to measure since it is just one angle. A high C2S of over 20 degrees correlates with poor Health-Related Quality of Life scores [32]. These results have been further corroborated by other groups including Hyun et al. [32] who found that a TS-CL greater than 22.2 degrees corresponded to severe disability (NDI > 25) and positive cervical sagittal malalignment, defined as a C2-C7 SVA greater than 43.5 mm.

Finally, an efficient assessment of concurrent thoracolumbar deformity is necessary. A helpful singular measurement in this regard is the **T1 pelvic angle (TPA)**. It simultaneously combines the measurement of sagittal deformity (as measured by T1 spinopelvic inclination, analogous to SVA) and pelvic compensation (pelvic tilt). The TPA is the angle subtended by a line from the femoral heads to the center of the T1 vertebral body and a line from the femoral heads to the center of the superior sacral end plate. Protopsaltis et al. [33, 34] showed excellent intra- and inter-observer reliability of this measurement.

Moreover the TPA remains constant, regardless of pelvic compensatory retroversion.

To summarize, we may include these four parameters as our key alignment parameters. The cSVA correlates well with every outcome measure. The T1S gives us information about the underlying thoracolumbar deformity. TPA gives us a quick and compensatory mechanism-independent overview of global thoracolumbar deformity. C2S tells us if a patient can compensate for the cervical spine deformity.

3. Clinical assessment

In the second step we evaluate the patient's symptoms and spinal function. There is as yet no standard measure of disability in cervical deformity. It is important to determine the patient's disability status with respect to concrete, everyday activities. Existing HRQL do not adequately capture CD disability and do not correlate with cervical malalignment. Therefore Stekas et al. [35] introduced the cervical deformity patient generated index (CD-PGI) that is designed to describe the most important limitations in health status for patients with cervical deformity.

Assessment of the patient's symptoms and complaints, as well as standing alignment, gait, and muscle weaknesses is essential. With progressive cervical malalignment, additional impairments can occur, including problems with horizontal gaze, coughing, swallowing and respiration. In addition, the patient is allowed to lie supine for at least five minutes in order to observe any passive correction of the neck deformity.

A full neurologic exam is needed. More severe deformity can lead to myelopathy and/or radiculopathy. Correlation between cervical kyphosis and severity of myelopathy is still under debate. Smith et al. [36] demonstrated correlation between cervical sagittal balance to myelopathy based on the Modified Japanese Orthopedic Association (mJOA) score. Additionally, we determine whether the patient is medically fit to undergo an extensive operation.

This raises the question of supine imaging which is considered the most realistic assessment of deformity as it does not require active extension. Unfortunately, the landmarks of the lower cervical spine used to assess lordosis are often obscured on plain radiographs. However, supine advanced imaging in the form of MRI or CT offers the simultaneous advantages of allowing for a truer assessment of lordosis, and clear visualization of landmarks in the lower cervical spine. It is recommended to request extensive supine sagittal imaging that includes the cervicothoracic junction and planned lower instrumented vertebra (LIV). Furthermore, these modalities are often obtained during routine workup of cervical deformity and therefore do not require any additional cost and radiation. The use of supine imaging before

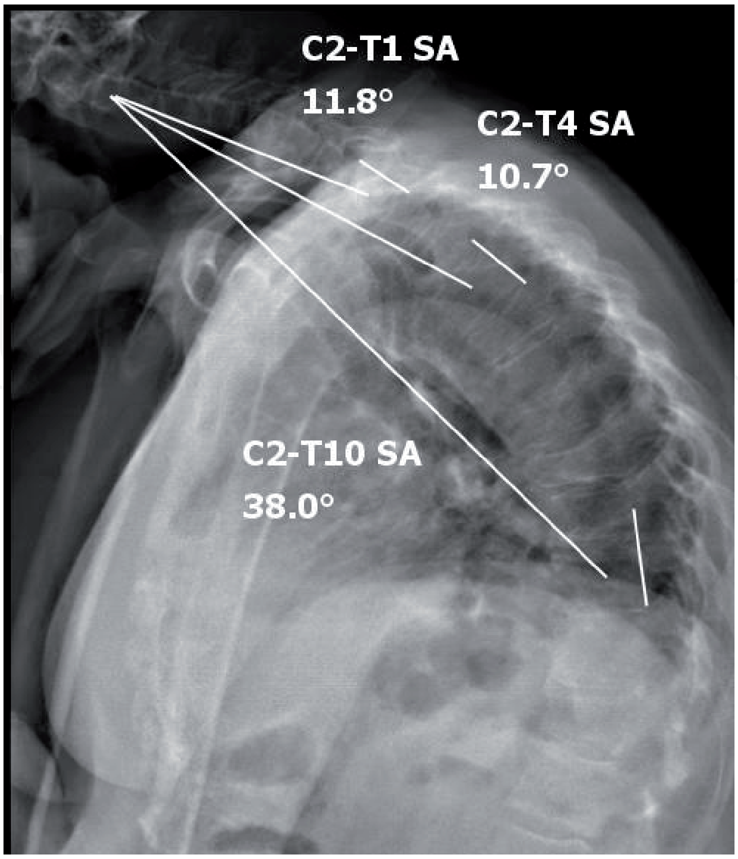

Figure 1.
Sagittal radiograph of a patient showing the measurement of C2-T1 SA, C2-T4 SA and C2-T10SA.

and during surgery has led to the development of new in-construct measurements, namely the C2-T1 sagittal angle (C2-T1 SA), C2-T4 sagittal angle (C2-T4 SA) and C2-T10 sagittal angle (C2-T10 SA) (**Figure 1**). These measurements have the advantage that they are independent of radiographic modality and patient position, as long as the fusion construct is stable. The **C2-T1 SA** is defined as the angle formed by a line from the centroid of C2 to the Centroid of T1, and a line parallel to the posterior body of T1. Similarly **C2-T4 SA** and **C2-T10 SA** are the angles formed by a line from the centroid of C2 to the Centroid of T4 and T10 respectively, and a line parallel to the posterior vertebral body of T4 and T10 respectively. Depending on the planned LIV, we further recommend adding one of these parameters to the other four main parameters, cSVA, T1S, C2S and TPA [28].

4. Classification

Currently there is ongoing focus on research to find a classification system that dictates treatment modality and predicts outcome. Ames et al. [37] (**Figure 2**) was built on basic deformity descriptors and five associated modifiers. Deformity descriptors differentiated deformity by type, ranging from sagittal to craniovertebral junction deformities, as well as regional location factoring thoracolumbar deformities. The selected modifiers accounted for various factors correlating with ACD and thoracolumbar deformity; Diebo et al. [38] described in his proposal of classification a two-step approach. Initially identifying the five most discriminate parameters are cSVA and T1 slope on lateral view, and maximum focal kyphosis, C2 slope and number of kyphotic levels on extension view. Those parameters were able to describe most of the deformity. On the second step his team proposed 3 distinct morphologies of sagittal cervical deformities based on lateral

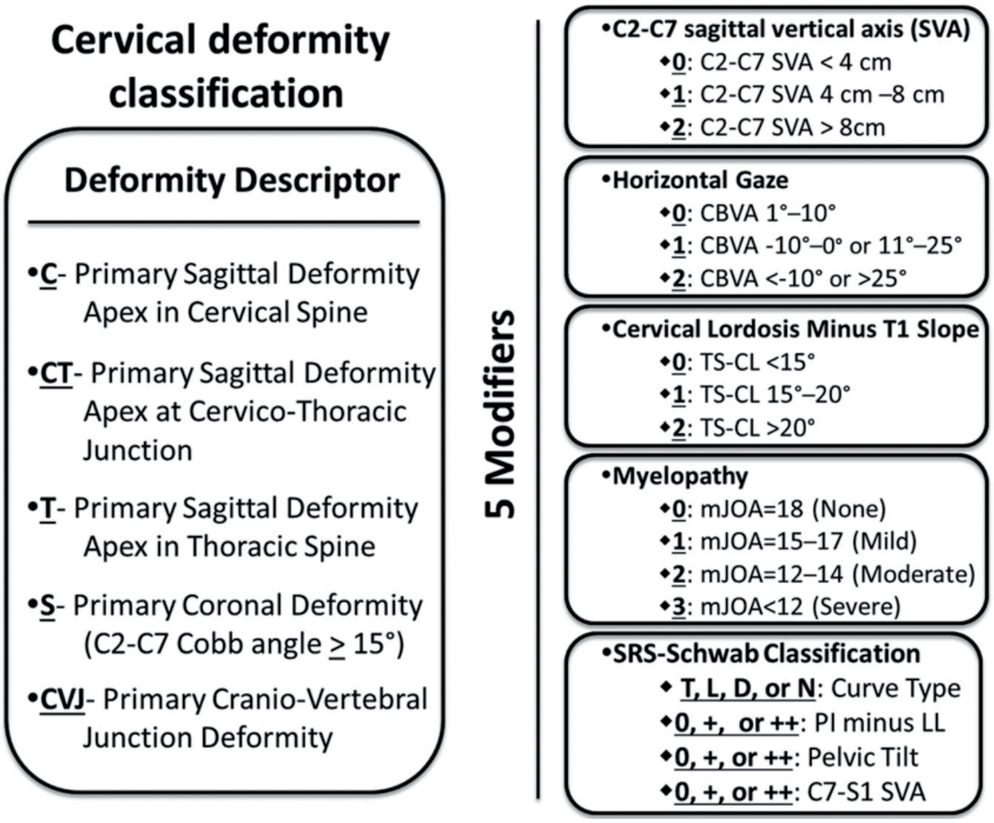

Figure 2.
Description of the CSD classification system, which includes a deformity descriptor and 5 modifiers. D = double; L = lordosis; N = none; T = thoracic.

and extension radiographs. Overall, the current classifications remain limited to radiographic or clinical description.

5. Surgical techniques

Ames et al. [39] proposed a cervical osteotomy classification scheme that ranges from least invasive to most invasive and includes: (I) partial facet joint resection, (II) complete facet joint/(Ponte) osteotomy, (III) partial or complete corpectomy, (IV) complete uncovertebral joint resection to the transverse foramen, (V) opening wedge osteotomy, (VI) closing wedge osteotomy, and (VII) complete vertebral column resection.

Osteotomies are the mainstay of treatment in deformity correction. In the thoracolumbar region, posterior osteotomies are well established, including opening wedge osteotomy and pedicle subtraction osteotomy (PSO). However, these techniques are limited in the cervical region due to the presence of the vertebral artery, the sensitivity of the cervical nerve roots to traction, and the small size of the cervical vertebrae. Pioneered by Simmons [40], a posterior column osteotomy with controlled osteoclasis of the anterior column of the cervical spine can result in significant improvement in cervical spine alignment and in the patients' ability to maintain forward gaze and adequately perform activities of daily living.

Osteotomies utilizing an anterior approach for cervical deformity corrections have been described by Riew [41] and Kim [41]. Common anterior techniques include anterior cervical discectomy and fusion (ACDF), cervical corpectomy, anterior osteotomy (ATO), and the Riew osteotomy [42, 43]. Anterior techniques can often be combined with posterior techniques to achieve circumferential spinal

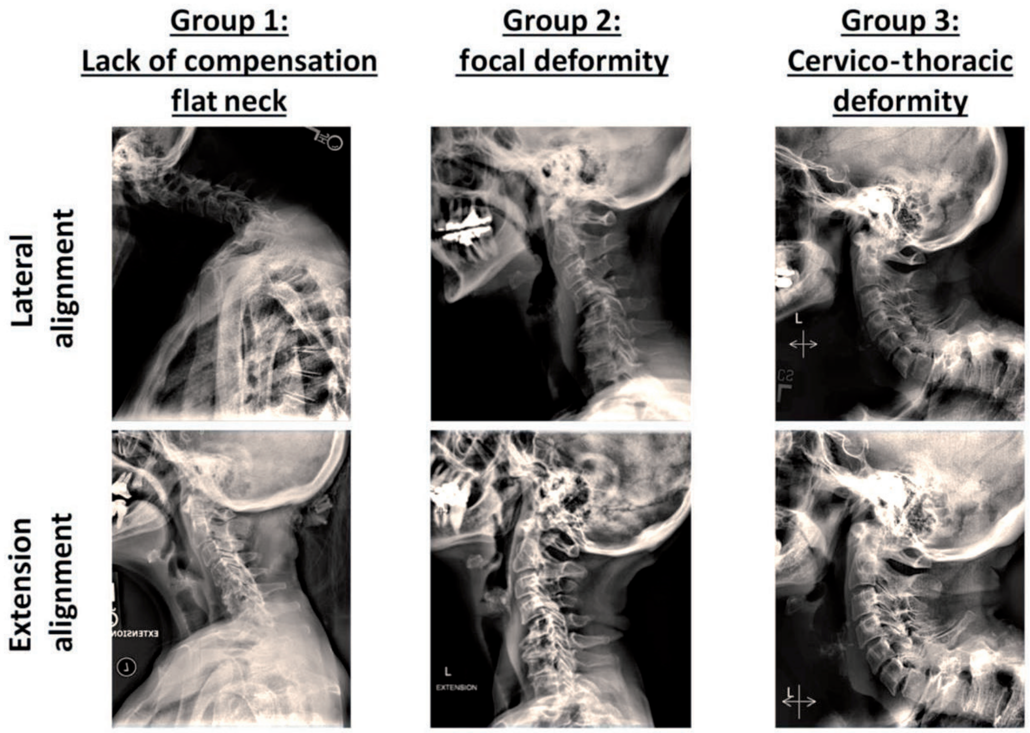

Figure 3.
New cervical deformity morphologies described by Diebo et al. [38]: Group 1 (46.1%): Flatneck with lack of compensation, largeT1S-CL, flexible CL; Group2 (30.8%): Focal deformity, large focal kyphosis between 2 segments, No large regional cervical kyphosis under the setting of a low T1S; group 3 (23.1%): Cervico-thoracic deformity, very large T1S, hyperlordosis of the cervical spine, no extension reserve left.

reconstruction. It remains inconclusive whether adding a posterior approach augments angular correction and improves stability [43]. As a general rule, the amount of lordosis obtained is about 3–5 degrees for single-level ACDF, 10 degrees for the Smith-Petersen osteotomy (SPO), 17 degrees for ATO, and up to 35 degrees for C7 PSO [44–46].

In severe cases, upper thoracic and cervical PSO's may not get the same correction as a Vertebral Column Resection (VCR). Hoh et al. [47] reported the use of two-stage (posterior–anterior) VCR for the treatment of ankylosing spondylitis. Garg et al. [48] reported the use of three-stage (anterior–posterior–anterior) VCR for a patient with kyphotic cervical deformity following tuberculosis infection. Funayama [49] reported a case of severe kyphotic deformity which showed an improvement from 75 degrees to 21 degrees with a three-stage VCR.

Several retrospective studies [23, 50, 51] presented a large potential of coronal and sagittal correction with posterior VCR. However this procedure can be associated with significant morbidity, particularly in the correction of kyphotic deformity.

Due to the complexity of the neurovascular anatomy in the cervicothoracic region, posteriorly based osteotomy techniques are challenging. Riew et al. [52] makes a case for combining ATO with SPO and posterior cervical fusion, which generated a mean angular correction of 28 degrees per level, providing equal or better corrections than isolated PSOs [9, 53–55] (**Figure 3**).

6. Planning the tailored strategy

In the pre-surgical planning, radiographic measurements of spinopelvic parameters are determined using validated software such as Surgimap (Nemaris Inc., New York, NY). The senior surgeon (TSP) maps out the correction with planning software.

Measuring Hounsfield units (HU) on clinical CT scans of the thorax, abdomen or pre-operative spine CTs demonstrated a reliable correlation between T values of the DEXA measurement and HU of the same vertebral body [56, 57].

Preoperative CT-scan determination of bone density can predict the risk of screw loosening and impact on the technical preferences [57] and has proven to be superior to a pre-operative DEXA scan in the assessment of screw loosening in degenerative spine disease [58].

The LIV is planned for an area with no kyphosis, that is, in an area of neutral alignment. Bone quality is evaluated with CT Hounsfield units, particularly at the LIV and LIV-1 level where failure tends to occur.

Subjacent reciprocal compensation is anticipated at the distal end of the instrumentation construct. The increase of thoracic kyphosis/(the DJK angle change) below the fusion is predicted with a mathematical formula, which includes the change in cervical lordosis (change in CL), and most importantly the actual change in construct alignment (change in C2-LIV SA) [59]:

$$\begin{aligned}\mathrm{DJKA}\left(\mathrm{DJKA}_{\mathrm{post}}\right).\mathrm{DJKA}_{\mathrm{post}} &= 9.365 + 0.315 * \left(\mathrm{C2} - \mathrm{LIV}_{\mathrm{post}}\right) \\ &\quad + 0.504 * \left(\mathrm{DJKA}_{\mathrm{pre}}\right) + 0.123 * (\Delta \mathrm{CL}) \qquad (1)\end{aligned}$$

The formula also includes the preoperative DJK angle, underscoring the importance of planning the LIV in a region where there is no preoperative kyphotic alignment.

7. Intraoperative assessment of correction

Fluoroscopy can be used to measure the focal correction during surgery after performing an osteotomy procedure. Next a 36 inch X-ray cassette that captures the entire fusion construct is recommended. The in-construct measurement appropriate for the patient's instrumentation can be measured (for example, C2-T10 SA for a posterior fusion from C2 to T10) (see **Figure 4**).

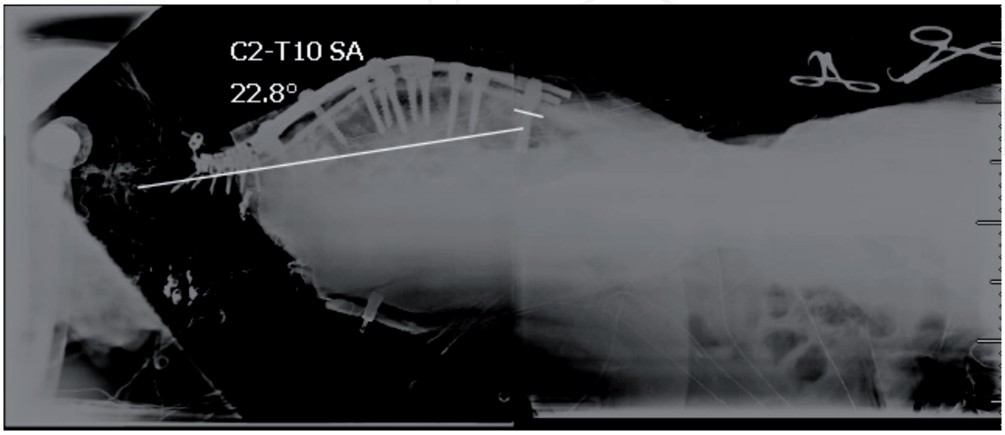

Figure 4.
The in-construct measurement appropriate for the patient's instrumentation can be measured during surgery (for example: C2-T10 SA for a posterior fusion from C2 to T10).

8. Intraoperative neuromonitoring

Intraoperative neuromonitoring is a tool with the goal of providing patients with limited morbidities and optimal outcomes during and after surgery. The aim of neuromonitoring during an operation is to provide the surgeon with a real-time analysis of spinal cord function at a time when there is still a possibility to correct any possibility of morbidity. Spine surgeons need to be aware of the low sensitivity and positive predictive value with neuromonitoring so that they rely more on their clinical and surgical judgment and interpret neuromonitoring with more scrutiny [60].

9. The DJK prevention strategy

Surgeons need to know when their intraoperative corrections are adequate to align CD patients optimally [61]. We propose a strategy of several steps that can be taken to minimize the risk of DJK. First is determination of the correct alignment to be achieved during surgery by utilizing the newly developed in-construct measurements. This involves anticipating the subjacent reciprocal changes to give a final result of a C2S of under 20 degrees and a cSVA of under 4 cm [62].

Secondly, the use of softer materials at the distal junction may protect against the development of Adjacent Segment Disease (ASD) and junctional kyphosis. In a retrospective case–control study by Han et al. [63] the use of cobalt chrome multiple-rod constructs (CoCr MRCs) versus titanium alloy two-rod constructs (Ti TRCs) were evaluated with a minimum of 1-year follow-up. They suggested that increasing the number of rods and their stiffness promotes proximal junctional kyphosis (PJK) in ASD surgery. PJK prevention strategies that should be considered for preventing DJK include minimizing the destruction of soft tissue at the Upper Instrumented Vertebra (UIV) (PJK) and therefore LIV (DJK) and using transition rods with softer metals [64].

Thirdly, optimization of bone health is critical. The role of pharmacotherapy in aiding implant fixation or fusion has been studied for bisphosphonates and teriparatide (Human recombinant PTH 1–34, Forteo, Ely Lilly, Indianapolis, IN). Zolendronate was found to make no statistically significant difference. Prospective trials [65] showed a significant advantage in prescribing teriparatide over bisphosphonate to aid fusion and lower the rate of pedicle screw loosening. However, the most recent published study by Oba et al. [66] must be evaluated carefully due to the short follow-up duration as well as the cost and the potential for serious side-effects with the use of teriparatide.

Teriparatide is very expensive, and due to the limited on-label indications it can be challenging to secure insurance coverage. However, in light of the costs associated with spinal fusion surgery and the importance of preventing osteoporosis-related complications as defined by Bjerke et al. [67], insurers are becoming more willing to consider off-label orthopedic indications for teriparatide. In addition, in most cases the patients do qualify based on their diagnosed level of osteoporosis. This emphasizes the importance of a pre-operative workup. The most commonly described and FDA-approved dosing schedule for teriparatide is 20 mcg/day. Yet, an effective [59] weekly dosing schedule of 56.5 mcg/week has been described for vertebral compression fracture (VCF) and spine fusion. Timing of treatment before and after spinal surgery is still evolving and may vary. Several studies suggest a benefit to initiating teriparatide 3 months before surgery, which is a challenge to insurance approval. Consequently, it has been suggested [60] that patients have at least 4–6 weeks of teriparatide therapy prior to surgical intervention. Following surgery, patients stay on teriparatide for at least 10 months, for a minimum of 12 months of total therapy.

Abaloparatide is a newer parathyroid hormone 1 receptor (PTH1R) agonist indicated for the treatment of osteoporosis in postmenopausal women with a high risk for fracture [61]. Because of its recent approval, abaloparatide is not mentioned in clinical guidelines for the treatment of postmenopausal osteoporosis, but its place in therapy is likely to be similar to that of teriparatide because the two drugs share a common mechanism of action. Use of either of these agents for more than two years is not recommended.

In a multi-center, multi-national, double-blind placebo-controlled clinical trial, Leder et al. [62] observed lumbar Bone Mineral Density (BMD) increases up to 6.7% over 24 weeks with abaloparatide versus only 5.5% and 1.6% in the teriparatide and placebo groups respectively ($p = <0.001$). Bilezikian et al. [63], in a Phase 2 randomized control trial of postmenopausal women aged 55–85 years, demonstrated consistently greater dose-dependent improvements in lumbar trabecular bone score by 12 weeks with abaloparatide when compared to teriparatide or a placebo. Trabecular bone score might correlate with subsequent improvement in pedicle screw strength [64]. Denosumab, a RANK-L inhibitor, has been approved by the FDA (Food and Drug Administration) and established in the treatment of osteoporosis, but its role in spine fusion has yet to be evaluated.

10. Conclusion

It has been estimated that the cost of healthcare in the United States is nearly twice as much as any other developed countries [65]. Therefore the prevention of complications and revision costs are becoming increasingly recognized and recent efforts have been made to qualify and quantify new prevention measures against failure. Passias et al. [66] have found that DJK is a significant predictor of surgical readmission after ASD operations. In Scheuerman patients DJK might be well tolerated without symptoms, loss of alignment or mechanical decompensation [67].

Our DJK prevention strategy has proved successful in providing tools for the surgeon to foresee the risks of failure and modify the treatment in order to prevent disability, complications and revision surgery in cervical deformity patients.

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