Themistocles S. Protopsaltis, MD

**Currently Accepted Radiographic Measurements of Cervical Deformity**

The importance of sagittal alignment has been well established in the thoracolumbar deformity literature.\(^1\)\(^-\)\(^5\) More recent studies are beginning to demonstrate that regional cervical sagittal alignment can also affect health related quality of life measures (HRQL). Primary cervical deformities need to be differentiated from compensatory cervical changes to malalignment in subjacent spinal regions. Studies have shown that deformities in the thoracic and lumbar regions can induce reciprocal changes in cervical spinal alignment which become compensatory mechanisms to maintain global standing alignment.\(^6\)\(^-\)\(^8\) Differentiating these compensatory changes in the cervical spine from primary cervical deformities is the first step in the analysis of cervical deformity. Conditions such as spondyloitic arthropathies, idiopathic cervical paraspinal myopathies and iatrogenic cervical kyphosis can create the most severe primary cervical deformities which can cause the “chin-on-chest” deformities that compromise horizontal gaze, swallowing, and breathing.\(^9\)\(^-\)\(^13\)

The majority of the literature on the subject of cervical deformity focuses on the subaxial cervical spine. A classic article demonstrating the link between cervical sagittal alignment and disability measures is that of Tang and colleagues; in a population of patients who underwent posterior cervical fusions, they showed that the postoperative C2-C7 sagittal vertical axis (cSVA) correlated with the Neck Disability Index (NDI) score and SF-36 Physical Component Score (PCS).\(^14\) Using linear regression analysis they determined that a cSVA greater than 4 cm corresponds to a moderate disability threshold.\(^14\) Likewise cervical kyphosis has been correlated with poor HRQOL outcomes.\(^6\)\(^,\)\(^12\)\(^,\)\(^15\) Cervical kyphosis can be progressive resulting in neurologic deterioration, including progressive myelopathy.\(^15\)\(^,\)\(^16\)
A cSVA > 4 cm and cervical kyphosis have been the most commonly reported definitions of cervical deformity in the literature.\textsuperscript{14,17} Using these definitions of cervical deformity Smith et al reported a 53\% rate of cervical deformity in patients also meeting criteria for thoracolumbar deformity.\textsuperscript{17} Ames et al recently proposed a standardized classification system of cervical deformity based on existing clinically relevant parameters within the context of global spinal alignment.\textsuperscript{18} It has been shown to have moderate inter-observer and intra-observer reliability, and should provide a common language for studies on quantifying the severity of primary cervical deformity.\textsuperscript{18}

However, existing definitions of cervical deformity may not be sufficient. For one, cervical kyphosis can be a normal feature of physiologic standing alignment, particularly among younger people who stand with a negative SVA.\textsuperscript{19,20} In a study on 106 subjects without neck pain, showed that 34\% had cervical kyphosis.\textsuperscript{20} Moreover, the cSVA can be affected by subjacent thoracolumbar mal-alignment.\textsuperscript{7,8} Smith and colleagues demonstrated that thoracolumbar deformity patients can have increased cSVA and this cervical mal-alignment resolves spontaneously with correction of the underlying thoracolumbar deformity.\textsuperscript{7}

Recent literature on the subject of cervical deformity has begun to focus on the important relationship between T1 slope and cervical lordosis as a means of gauging the presence of cervical deformity.\textsuperscript{21-23} The relationship between pelvic incidence and lumbar lordosis has been used effectively as a measure of lumbo-pelvic alignment and it is an effective perioperative tool for planning and executing corrections in lumbar flatback deformity.\textsuperscript{3} In fact, sacral slope is more highly correlated with lumbar lordosis and this relationship is mirrored in the cervical spine where T1 slope has been shown to correlate with cervical lordosis, when this relationship is disrupted, subaxial cervical deformity is present or the underlying thoracolumbar deformity is so severe that it creates an excessively large T1 slope that outstrips the ability of cervical spine to balance alignment.\textsuperscript{21-25} Protopsaltis et al demonstrated that even in the presence of underlying thoracolumbar deformity, if the mismatch between T1 slope and cervical lordosis (TS-CL) exceeded 17\(^\circ\), then cervical deformity is present.\textsuperscript{21} Ames and colleagues demonstrated that among patients who had
undergone cervical fusions, a mismatch exceeding 20° corresponded to a cSVA of more than 4 cm, the published threshold for cervical deformity.\textsuperscript{22}

Therefore, the TS-CL relationship can be used as preoperative planning tool to determine the amount of cervical lordosis necessary to improve regional cervical sagittal alignment.\textsuperscript{21,22}

Looking further into the TS-CL measurement, the relationship distills down to the C2 slope. If $\text{TS-CL} = \text{T1 slope} - (\text{C7 slope} - \text{C2 slope})$, and T1 slope approximates C7 slope in most cases, then $\text{TS-CL} \approx \text{C2 slope}$. Protopsaltis et al., proposed C2-Slope as a singular cervical deformity parameter.\textsuperscript{26} C2 Slope correlated with both upper cervical and subaxial cervical alignment parameters. C2-Slope has an extremely high correlation with TS-CL ($R=0.98$, $p<0.001$) which is explained by the fact that C2-Slope is a mathematical approximation of TS-CL and therefore C2-Slope is a simple substitution for it (Figure 1). Significant correlations between the upper and lower cervical spine exist in patients with cervical deformities, confirming the existence of inherent compensatory mechanisms to maintain overall balance. The C2-Slope is a useful marker of overall cervical sagittal alignment, acting as a link between the occipitocervical and cervico-thoracic spine. The C2-Slope defines the presence of a mismatch between cervical lordosis and thoracolumbar alignment required to maintain horizontal gaze.\textsuperscript{2}
Surgical planning for cervical deformities begins with obtaining appropriate imaging. In addition to MRI and CT scan, long cassette x-rays provide an assessment of the full spine to identify concurrent thoracic and lumbar deformities that may be contributing to the cervical deformity. Smith and colleagues demonstrated the importance of full spine radiographs in a survey study in which 30% of spine surgeons would modify their surgical plan when presented with a long cassette radiograph showing thoracolumbar malalignment. The C2-T1 Pelvic Angle (CTPA) and T1 Pelvic Angle (TPA) have been proposed as a means of determining the relative proportion of cervical and thoracolumbar deformity, respectively (Figure 2). These measures require full-length radiographs with visualization from C2 to the pelvis. When planning cervical fusions, the clinical scenarios in which full spine radiographs should be obtained have not been well established. When the T1 tilt falls outside the range of 13 to 25 degrees, Knott et al recommended long
cassette radiographs in order to evaluate thoracolumbar malalignment.\textsuperscript{32} Kleinberg and colleagues showed that when the T1 slope exceeds 32 degrees, underlying thoracolumbar deformity is likely to be present with a sensitivity of 69\% and a specificity of 69\%.\textsuperscript{35} One potential reason for insufficient correction is the failure to recognize underlying thoracolumbar deformity that can contribute to the cervical malalignment. Sagittal malalignment may persist if the thoracolumbar malalignment is not recognized and addressed concurrently with cervical deformity. Similar to the problem of proximal junctional kyphosis in thoracolumbar deformity correction, unrecognized subjacent deformity may also contribute to distal junctional kyphosis which may further degrade the sagittal correction of the cervical spine.

Figure 2: The C2-T1 Pelvic Angle (CTPA) is a global angular measure of cervical sagittal balance and a correlate of C2C7 plumbline. CTPA is the angle of a line from center of C2 to femoral heads (FH) and a line from FH to center of T1. The T1 Pelvic Angle (TPA) is a measure of global sagittal alignment and a
correlate of C7 SVA. CTPA and TPA account for the relative proportion of cervical and thoracolumbar deformity respectively.

In surgical planning, the T1 slope cervical lordosis relationship can be utilized to determine the deficit of cervical lordosis in a given deformity.\textsuperscript{21-22} If the T1 slope is greater than 30 degrees or if the T1 pelvic Angle is greater than 20 degrees then an underlying thoracolumbar deformity may need to be addressed concurrently which may be contributing to the cervical sagittal malalignment.\textsuperscript{2,32} Kim and colleagues quantified the magnitude of angular and translational corrections obtained by common osteotomies in the cervical spine.\textsuperscript{33} They showed that an anterior osteotomy combined with a posterior Smith Peterson osteotomy can provide a similar correction as a cervical pedicle subtraction osteotomy but with less blood loss. However, the determination of anterior or posterior approach requires an assessment of the stiffness of the cervical spine and whether there is anterior or posterior fusion. Hann and colleagues proposed an algorithm for planning the surgical approaches based on whether the cervical deformity is fixed or flexible.\textsuperscript{34} Ames and colleagues described a reproducible cervical osteotomy classification based on increasing grades of osteotomy magnitude.\textsuperscript{18} These studies provide a common language for communicating and planning cervical deformity corrections.

Future directions in cervical deformity will require a reassessment of the clinical impact of these cervical deformities. While a handful of studies have demonstrated correlations between cervical alignment parameters and existing HRQoL measures such as the NDI and SF-36, more recent studies on cervical deformity have failed to corroborate these correlations.\textsuperscript{29} Complicating this fact is the wide range of cervical deformities and their etiologic factors such as iatrogenic deformity after fusion, focal cervical kyphotic deformities, and flexible and fixed chin-on-chest deformities resulting from dropped head syndrome and ankylosing spondylitis. While existing measures such as the NDI have been shown to be relevant in common degenerative pathologies, they may not assess and capture the disabling features inherent in cervical sagittal deformity, such as loss of
horizontal gaze, dysphagia, dyspnea and walking difficulty. Further study is warranted to define assessment domains that are specific to cervical sagittal malalignment.

References


35. Klineberg, Carlson, Protopsaltis et al. Can Measurements on Cervical Radiographs Predict Concurrent Thoracolumbar Deformity and Provide a