Review Article

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Latest knowledge on a comprehensive understanding of cervical deformity and selection of effective treatment methods using recent classification systems: a narrative review

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Surgical treatment for patients with cervical spine deformities is challenging for both patients and doctors. For successful surgical treatment, mastery of processes is important to objectively evaluate and classify the degree of deformity. Recently, efforts have been increasing to systematically understand, evaluate, and effectively treat complex cervical spine deformities. Various parameters are being developed to quantify and objectively evaluate the degree of cervical spine deformity, and classification methods are being introduced to help establish the treatment scope by categorizing it according to the degree of deformity. However, a comprehensive and systematic understanding of complex deformities using only the currently introduced classification methods and related knowledge is not easy. Through this review, we aimed to introduce various classification methods and their pros and cons to evaluate cervical deformities, analyze their meaning, and provide a basic understanding of the evaluation and classification of patients with cervical spine deformities. This review also aimed to aid in the decision-making process for the treatment of cervical spine deformities by presenting a structured treatment algorithm based on recently known classification systems and lay the foundation for efficient treatment.

Keywords: Cervical deformity; Evaluation; Classification; Treatment algorithm; Surgical procedures

Introduction

Cervical spine deformity (CD) not only causes pain or dysfunction but also causes the cervical spine to deviate from its normal alignment with the spine in other areas or pelvis, makes it difficult to maintain horizontal vision, significantly reduces quality of life, and leads to falls. It increases the risk of morbidity and significantly increases the mortality rate.

Therefore, various efforts have been made to systematically understand, evaluate, and effectively treat cervical deformities. Different indices and numerous parameters have been published to objectively evaluate the state or severity of the deformity that causes the cervical spine to deviate from its normal alignment. Moreover, classification methods that can be evaluated according to the degree of deformity and serve as a guide for surgical treatment have been introduced.

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However, to systematically and effectively understand complex cervical deformities, the currently introduced classifications are highly complex and numerous; thus, determining which parameters are meaningful is difficult. In addition, current classification methods focus on explaining some deformities; however, they do not comprehensively explain all cervical deformities. Therefore, persuasive treatment guidelines are insufficient.

This narrative review aimed to aid the decision-making process for the treatment of CDs by presenting a structured treatment algorithm based on recently known classification systems. Accordingly, this review is intended to systematically analyze, evaluate, and classify CDs and provide guidelines for efficient treatment for doctors who wish to study CDs, starting with an understanding of the process of achieving normal cervical spine alignment and balance.

Cervical Curvature, Shape, and Alignment

To understand CD, the normal curve of the cervical spine must be understood first. Many studies have explained that a normal cervical spine must have a lordotic curve, and many people probably do not question that the cervical lordotic curve is a normal alignment. This might be even truer in patients indicated for surgery. After surgery, regardless of the surgical method, everyone commonly makes efforts to maintain cervical lordosis (CL) as much as possible. However, if the patient's preoperative cervical spine alignment had a kyphotic curve rather than lordotic and no special problems hinder the maintenance of the alignment or balance not only with the cervical spine, but also with the thoracic spine, lumbar spine, and pelvis before surgery, clinicians must think about whether it would be desirable to make the kyphosis curve that the patient had maintained without any problems before surgery into as much lordosis as possible.

According to Khalil et al. [1], when the curves of the cervical spine were classified in asymptomatic in adults (n=144), most showed lordosis (C2–7 >5°, 41%), and few showed kyphotic curves (C2–7 <5°, 31%) and straight (C2–7 <-5° to 5°>, 27%) curves. However, when kyphosis and straight curves are combined, the number of people with kyphosis and straight curves is higher and even more than that of people with lordosis. In another study, Virk et al. [2] investigated asymptomatic cases, 32.1% of the patients showed a kyphotic curve, and they reported that the kyphotic curve of the cervical spine may be physiological. Thus, cervical kyphosis can be physiological. In a previous study [3], numerous people without symptoms also had cervical kyphosis. Of the 958 currently asymptomatic individuals, approximately one-quarter (n=252, 25%) had a kyphotic curve, and uniquely, most of them had a kyphotic curve in a neutral state with their heads raised. When the head was extended, the lordosis curve was restored (reducible type); however, in approximately 1/6 (n=42) of the patients with kyphosis, the kyphotic curve was not restored even when the head was extended (non-reducible type).

Therefore, the most common cervical spine curve seen in normal people is a lordotic curve; however, quite a few or similar numbers of patients have kyphotic or straight curves in their ordinary lives.

Correlations and Reciprocal Change–Cervical Balance

How does this diversely curved cervical spine maintain its function while interacting with the surrounding spine, thoracic spine, lumbar spine, and pelvis?

Khalil et al. [1] analyzed how the cervical spine, other vertebrae, and pelvis interact to maintain horizontal vision in asymptomatic cases. The correlation was analyzed by assessing the correlation between the parameters related to the cervical spine known to date and the parameters of the thoracic spine, lumbar spine, and pelvis. According to the study, regardless of the curve of the cervical spine and the shape of the curve, that is, kyphosis, lordosis, and straight, the cervical spine had a high correlation with parameters within the cervical spine. T1–CL mismatch was correlated with all various parameters of the cervical spine but was particularly highly correlated with the C2 slope, and the cervical sagittal vertical axis (SVA) was an index that was highly correlated with the global cervical spine. The correlation among these parameters showed a meaningful correlation between parameters from the head to the cervical and thoracic spine; however, the correlation between parameters decreased when progressing down to the lower part of the cervical spine, that is, the lumbar spine and pelvis.

Thus, although there are curves of various shapes in the cervical spine, balancing is achieved through interaction with surrounding structures. This suggests that primary changes occur in structures close to the cervical spine (head and thoracic spine), followed by structures moving far away (Fig. 1).

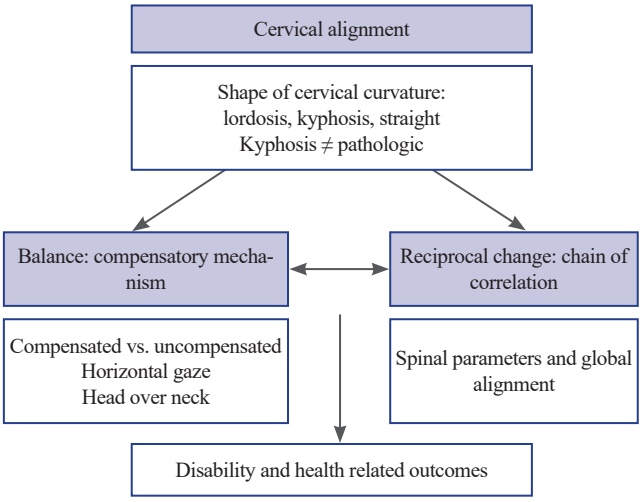


Fig. 1. This illustration describes the link of cervical alignment, balance, and reciprocal changes on our spinal system. When 'the Link' interrupted, disability and health related outcome arises.

In people with cervical kyphosis (C2–7 <0°), C2 slope, C0–2 range of motion (ROM), and C1–2 ROM, which are parameters of the movement and ROM of the upper cervical spine (C0–2), increase to maintain horizontal vision. Moreover, the T1 slope (T1S) and thoracic kyphosis (TK) decrease, and the entire global alignment moves posteriorly (posterior global alignment). On the contrary, in people with CL (C2–7 >0°), the lordosis curve of the cervical spine is already well maintained, and so does the movement or ROM of the upper cervical spine (C2 slope, C0–2, and C1–2 ROM), which is compensatory to maintain a horizontal view, decrease accordingly. Thus, there is no need to grow to maintain horizontal vision. It is followed by the T1S and TK increases, and the global alignment of the entire spine moves forward, creating an interaction to achieve balance (Fig. 2).

The ability to maintain a stable balance of the entire spine through the interaction of the various curves and alignments of the cervical spine with structures above and below, such as the surrounding spine, pelvis, and head, while fulfilling the purposes of surgery such as correcting nerve decompression and instability is important. However, if the series of interactions and balances that attempt to align the sagittal or coronal planes are disrupted, a strain is placed on surrounding muscles and ligaments, maintaining horizontal vision is difficult, which is a natural function of the cervical spine, and aligning the head directly above the cervical spine. Finally, the patient develops into a patient with cervical deformity, which causes severe cervical pain, difficulties with walking, swallowing, and breathing, and nerve damage.

According to a report by Smith et al. [4], patients

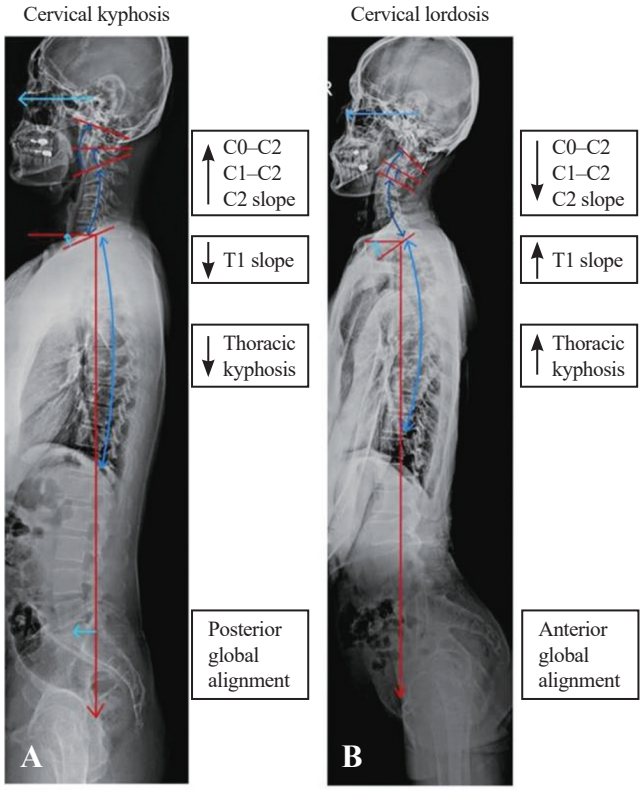


Fig. 2. (A, B) This figure shows the difference of global alignment of spine between cervical kyphotic patients and lordotic patients. The increase and decrease of C0–C2 angle, C1–C2 angle, C2 and T2 slope, thoracic kyphosis, and pelvic global alignment are in opposite direction between cervical kyphosis versus lordosis group.

with CD have a disease burden similar to that of blind people, regardless of the type of the deformity, and have an even more severe disease burden than myocardial infarction, heart disease, and cancer. Because horizontal vision is limited, the risk of falls is high, the morbidity rate of postoperative complications and diseases is very high, and the all-cause mortality rate is as high as 9.2%. Thus, systematic analysis, evaluation, and treatment of patients with CD are necessary.

Key Parameter Assessment

As explained above, if the series of interactions that maintain balance through interactions with the surrounding spine and pelvis are disrupted, regardless of the shape of the curve of the cervical spine, a strain occurs on the surrounding muscles, ligaments, and bone structures. This becomes the beginning of deformity and leads to worse outcomes. Several parameters have been developed to effectively explain how the cervical spine balances with surrounding structures. Numerous studies have reported on meaningful parameters that affect the health-related quality of life (HRQoL)

after cervical spine treatment and indices related to CD. However, because of excessive information and complex analysis, determining what parameters should be used for analysis in clinical practice is difficult. Many parameters reported to date are not related only to patients with CDs. Therefore, we will explain several key parameters that are known or currently widely used to be related to the classification and evaluation of CD.

Parameters Determining Cervical Spine Deformity

C2–7 sagittal vertical axis

Tang et al. [5] and Tan et al. [6-8] measured C2–7 SVA in all age groups. They found that >40 mm could cause disability. The C2–7 SVA is a widely used measure of regional sagittal alignment and has been associated with HRQoL metrics [8].

Chin–brow–vertical angle

This index is used to evaluate horizontal visibility and is used when planning for cervical kyphosis correction. It was most appropriate to maintain a horizontal field of view when the angle was 10°< chin–brow–vertical angle (CBVA) <−10°.

Modified Japanese Orthopaedic Association scores

Sagittal imbalance of the cervical spine is correlated with the severity of myelopathy. Smith et al. [9] and Scheer et al. [10] reported that the Pearson correlation between C2–7 SVA and cervical kyphosis was 0.282 (p=0.035).

T1 slope

In 2010, Knott et al. [11] stated that T1S is a useful index for evaluating sagittal imbalance, and that if T1S was >25°, a positive sagittal imbalance (C7 SVA) of at least 10 cm occurred. According to Ayres et al. [12], T1S is an indicator of the connectivity between the cervical spine and thoracolumbar spine, and if this parameter is large before surgery, there is overall global sagittal malalignment. In addition, when the angle is >30°, other spinal indices such as TK, SVA, T1 pelvic angle (TPA), pelvic incidence minus lumbar lordosis (PI–LL), and pelvic tilt (PT) are all high. In 2021, Scheer et al. [10] reported that T1S was highly correlated with CL, and along with Schwab et al. [13] and Protopsaltis et al. [14], the quality of life was significantly worse when the T1S–CL >15° (significantly poorer HRQoL). T1S–CL <15° should be the goal when surgically treating cervical deformity.

In particular, according to Protopsaltis et al. [14], the C2–7 plumb line explaining cervical sagittal deformity of 4 cm corresponds to the T1S–CL threshold of 17°, and T1S–CL was significantly correlated with the cervicothoracic pelvic angle (CTPA), a novel global sagittal parameter. Like the relationship between PI–LL in thoracolumbar spine deformity correction, the T1S–CL relationship was said to be important in the surgical treatment of patients with CD.

C2 slope

As an important single parameter related to treatment outcomes (patient-reported outcome measures [PROMs]) and HRQoL of patients with cervical deformity, a large C2 slope significantly reduces quality of life and shows poor results in Neck Disability Index (NDI), modified Japanese Orthopaedic Association (mJOA), Numeric Rating Scale neck, and EuroQoL 5-Dimension (EQ5D). When the C2 slope was 20°, NDI and EQ5D showed a correlation with moderate disability. The C2 slope showed a high correlation with T1S–CL (r=0.98 p<0.001), and it is mathematically calculated as follows: T1S–CL=C2 slope. This can be explained when the CL is equivalent to the C7 slope–C2 slope, and T1S is viewed as a similar value to C7 slope [15].

Therefore, based on the above parameters related to HRQoL, deformity correction is considered when C2–7 SVA >40 mm, T1S–CL >15°, C2 slope >20°, and CBVA >10°.

T1 pelvic angle

This parameter is important as a global sagittal deformity evaluation index that explains the relationship between the thoracolumbar spine and pelvis. TPA, along with SVA and PT, describes the relationship with the surrounding spine other than the cervical spine and pelvis and is related to HRQoL [16]. There is a reason why the TPA is more important in the evaluation of patients with deformity than other parameters that serve as indicators of global sagittal alignment that explains the relationship between the pelvis and spines other than the cervical spine. For instance, even if the PT increases because of a large sagittal deformity, it may appear as if no deformity occurs if a compensatory mechanism occurs through pelvic retroversion.

However, the TPA, along with the CTPA, is not affected by PT and always shows a constant value regardless of pelvic retroversion. The CTPA has a high correlation with the C2–7 plumb line, a global analog of cervical sagittal balance. The CTPA and TPA accurately reflect the degree of deformity of the cervical and thoracolumbar spine, respectively. According to Ryan et al. [17], when the TPA was >20°, most patients showed Scoliosis Research Society (SRS)-Schwab modifier ++ or +SVA/+PT.

In summary, the following key alignment parameters should always be considered when establishing a comprehensive evaluation or plan for cervical deformity. The C2 slope shows whether the CD can compensate for each other as a single parameter that measures the T1S–CL, and T1S explains the relationship with the thoracolumbar spine deformity below the cervical spine and how much CL needs to be restored. The TPA is an index evaluating global thoracolumbar deformity. These indicators play a key role in determining the area and degree of correction for patients with deformities.

Classification Guidelines for Appropriate Treatment

Based on the parameters described above, several authors are rushing to introduce various classifications to help classify and evaluate patients with deformities. Some commonly used and known classifications are as follows.

Ames-International Spine Study Group classification

In 2015, Ames et al. [18] introduced the CD classification system. Based on the static image, it was classified according to where the deformity apex is located, and cervical SVA, CBVA, T1S–CL, mJOA, and SRS-Swab classification were used as key parameters to classify and express the degree of deformity (Fig. 3).

This classification system begins with five "descriptors" that provide a broad stratification of deformity types. The first three descriptors correspond to primarily sagittal deformities, with the apex of the deformity being the distinguishing feature: type "C" if the apex is in the cervical spine, type "CT" if it is at the cervicothoracic junction, and type T if it is in the thoracic spine. The fourth descriptor is for primarily coronal deformities that have a C2–7 coronal Cobb angle >15° (type "S"), and the fifth one is for primarily craniovertebral junction abnormalities (type "CVJ").

Once a CD is assigned one of these descriptors, five modifiers are then applied to incorporate sagittal, regional, and global spinopelvic alignment features as

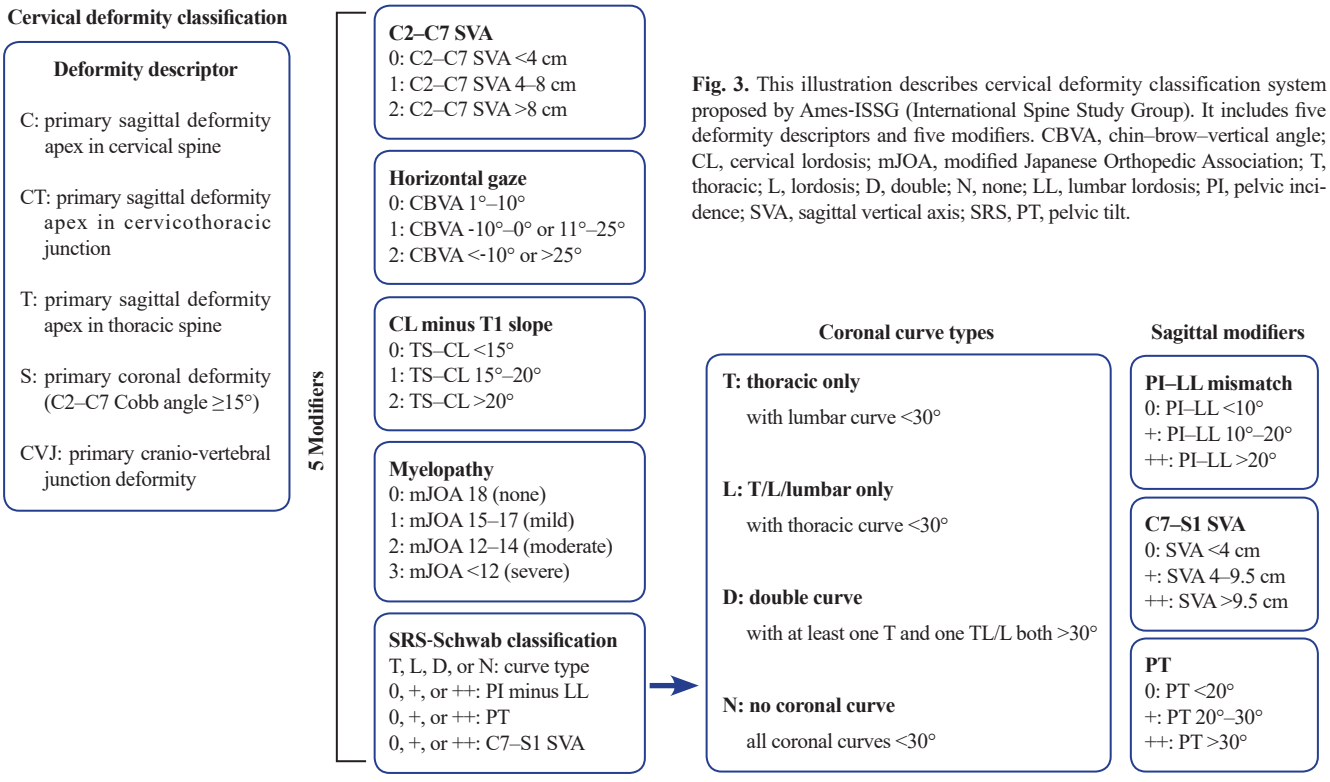


Fig. 3. This illustration describes cervical deformity classification system proposed by Ames-ISSG (International Spine Study Group). It includes five deformity descriptors and five modifiers. CBVA, chin–brow–vertical angle; CL, cervical lordosis; mJOA, modified Japanese Orthopedic Association; T, thoracic; L, lordosis; D, double; N, none; LL, lumbar lordosis; PI, pelvic incidence; SVA, sagittal vertical axis; SRS, PT, pelvic tilt.

well as myelopathy. The first modifier is to describe the translation of the cervical spine in the sagittal plane, and the C2–7 SVA was chosen because it is associated with PROMs such as the Short-Form 36 physical component score, NDI, and the mJOA score for myelopathy [8,15]. Tang suggested that C2–7 SVA of >4 cm is associated with worse NDI scores; thus, the modifier was scored accordingly. A C2–7 SVA of <4 cm is given a "0," 4–8 cm is given a "1," and >8 cm is given a "2." The second modifier is the CBVA, given the importance of the horizontal gaze. If the CBVA is 1°–10°, the score is "0," if it is −10° to 0° or 11°–25°, the score is "1," and if the CBVA is <−10° or >25°, the score is "2." The third modifier is the T1S–CL, which is a measure of regional alignment and is analogous to the mismatch between the pelvic incidence (PI) and lumbar lordosis (LL) that is central to thoracolumbar deformity. A score of "0" indicated T1S–CL <15°, a score of "1" for a T1S–CL of 15°–20°, and a score of "3" for T1S–CL >20°. This was defined by expert opinion, not by the objective PROM-related data. The fourth modifier is based on myelopathy because severe cervical kyphosis can cause axonal stretch, spinal cord injury, and ischemia. The mJOA was utilized in this study because it is a widely accepted scale for quantifying cervical spondylotic myelopathy and because it has been correlated with cervical sagittal balance [3,15]. The modifier was defined as follows: a score of "0" if the mJOA is 18 (no myelopathy), a score of "1" if the mJOA is 15–17 (mild myelopathy), a score of "2" if the mJOA is 12–14 (moderate myelopathy), and a score of "3" for JOA <12. The fifth and final modifier is the SRS-Schwab classification for thoracolumbar deformity, which has been linked to HRQoL measures [17]. This modifier is based on the understanding that cervical and thoracolumbar deformities can be interdependent. The intra- and interobserver reliabilities of this classification suggested moderate agreement; thus, it is a useful starting point for categorizing CDs. However, certain components were introduced here without definitively proving that they are responsible for the health effect of symptomatic cervical deformity. This has been corroborated by Bakouny et al. [19], who found that two of the modifiers—CBVA and T1S–CL—are not specific to patients with CDs and can be seen in asymptomatic adults [18].

Despite efforts to classify cervical deformities and evaluate them according to the degree of deformity using a relatively early classification method, most classifications were made based on expert opinions rather than on objective data on patients with actual deformity. Evaluating the degree of deformity in various movements using a static image is difficult, and regrettably, it was not possible to provide treatment guides such as surgical methods according to classification.

Koller-Cervical Spine Research Society Europe classification

In 2019, Koller et al. [20] classified CD by including both regional alignment and global balance based on the static image. The Cervical Spine Research Society (CSRS)-Europe was also established (Fig. 4). It does provide a useful and efficient tool for surgeons. Type A refers to patients who have cervical or cervicothoracic kyphosis but have reasonable regional and global balance as measured by the C2–7 SVA and the C2–S1 SVA.

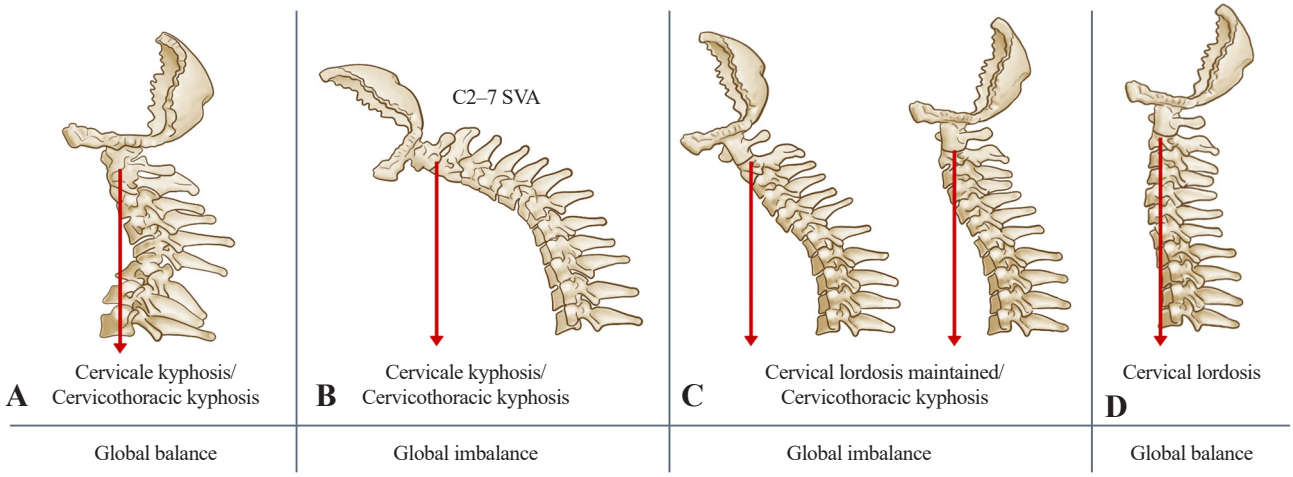


Fig. 4. (A–D) This illustration describes classification of cervical sagittal balance according to the shape of cervical and cervicothoracic spine proposed by the Cervical Spine Research Society. The cervical balance measures (C2–C7 sagittal vertical axis [SVA]) and also measures of global balance (C7–S1 SVA). For cervical regional balance, measures suggesting a physiologic range in healthy individuals include a C2–C7 SVA of about 20–30 (±10) mm. For trunk imbalance, measures of imbalance include a C7–S1 SVA and C7-plumb line falling anterior to the hip axis.

Type B refers to patients who have cervical or cervicothoracic kyphosis leading to a large C2–7 SVA and a large C2–S1 SVA, signifying regional and global imbalance. Type C is for patients with cervicothoracic kyphosis in whom lordosis can be partly compensated, but who nevertheless have a global imbalance. Finally, type D refers to patients who have sufficient CL to achieve global balance. Efforts were made to relatively simplify and easily classify patients with complex CDs; however, the classification was performed only on static images of the cervical spine. It also does not rely on a combination of radiographic parameters that are linked to HRQoL measures; therefore, it is difficult to know the comprehensive relationship with the image that includes the entire spine and there is no explanation of the relationship with various parameters or treatment methods.

Han Jo Kim-International Spine Study Group classification

Unlike other classifications, Kim et al. [21] introduced a classification based on dynamic images. Alignment and apical location were classified based on dynamic radiograph images, and surgical-level selection and surgical strategy were proposed (Fig. 5).

Based on the dynamic image, the two groups are distinguished depending on whether the patient can recover the CL by the given T1S in the flexion–extension side image. If the CL is recovered by the given T1S during extension, the deformity is limited to the cervical spine (group 2, focal deformity), and if recovery is not achieved (group 1, flat neck), the surgical area should be included from C2 to T1–3. The remaining type is a case where the deformity is present in both the cervical and thoracic spine, and the T1S is extremely high. To recover the normal curvature, three-column osteotomy (3CO) may be necessary, and lower instrumented vertebra (LIV) should be stopped at the mid-lower T spine. As a strength, it evaluates the patient and suggests an effective treatment range by considering the recovery ability of the cervical spine not only based on the patient's static images but also in a dynamic state using flexion–extension images, making this classification system unique when compared with previously published classifications. This classification system can also help identify the main driver of a patient's cervical deformity. Most patients in group 1 (flat neck group) have a cervicothoracic driver, most in group 2 (focal deformity group) have a cervical driver, whereas the CT group had usually a thoracic or thoracolumbar driver of the deformity. Another unique feature of this classification system from the approach by Kim et al. [21] is that cervical sagittal alignment parameters, as measured on neutral radiographs, do not appear to correlate with HRQoL measures. This is consistent with the aforementioned work by Bakouny et al. [19], who showed that the C2–7 SVA and CBVA modifiers from the Ames-International Spine Study Group (ISSG) classification are seen in asymptomatic adults. However, it has limitations; if it is applied to patients with deformity who are not good at extension, the relationship with global alignment is insufficient, and the explanation is also limited in patients with highly problematic high C2 tilt and high T1S. Therefore, this aspect is suitable for flexible deformity.

Protopsaltis-International Spine Study Group classification

Protopsaltis et al. [14-16] introduced the importance of the C2 tilt and T1S in explaining deformities. In this classification, the relationship between the thoracolumbar deformity and the compensatory action of the cervical spine was classified into three (Fig. 6). In type 1, the thoracolumbar spine is the major site of deformity, and the cervical spine compensates well and usually re-

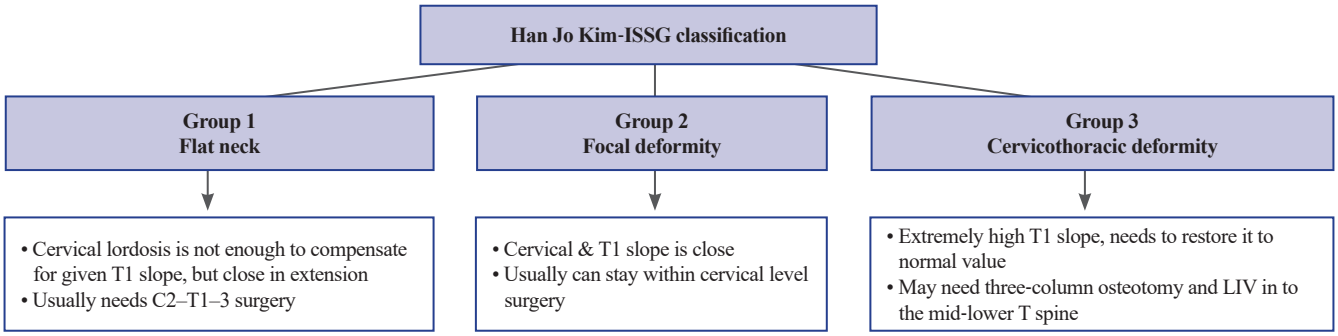


Fig. 5. This illustration describes Han Jo Kim-International Spine Study Group (ISSG) classification about sagittal cervical alignment. Three groups are distinguished with five parameters: T1 slope, C2–C7 angle, maximum kyphosis, thoracic slope minus cervical lordosis, and cervical sagittal vertical axis in dynamic radiograph image. Each group shows a difference in the level of surgery. LIV, lower instrumented vertebra.

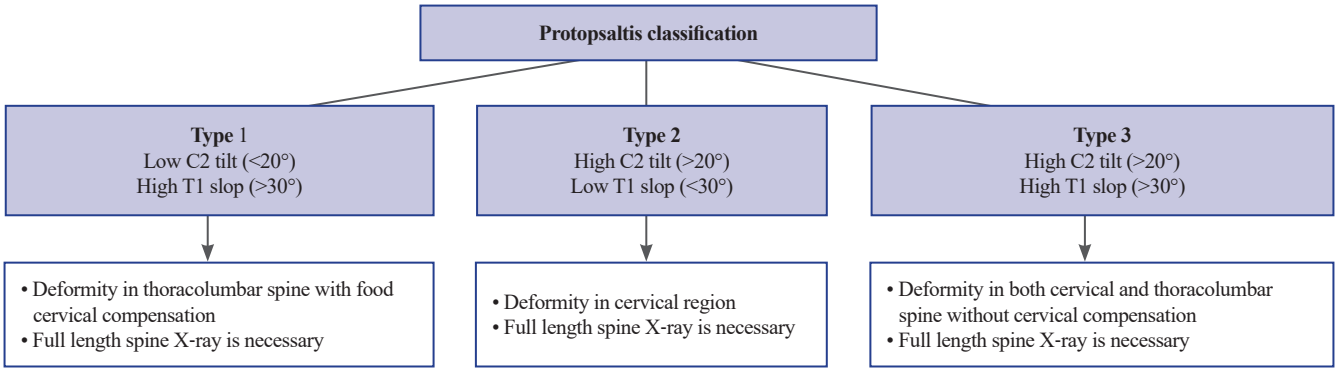


Fig. 6. The illustration describes Protopsaltis classification that classifying into three types according to C2 tilt and T1 slope. For each type, there are differences in the spine level that the deformity involvement, the compensation relationship, and the necessity of full-length spine X-ray.

quires full-length spine X-ray imaging (low C2 tilt <20°, high T1S >30°). In type 2 (high C2 tilt >20°, low T1S <30°), the deformity is within the cervical spine, and full-length spine X-ray images may not be necessary. In type 3 (high C2 tilt >20°, high T1S >30°), the deformity is located in both the cervical and thoracolumbar spine and the cervical spine does not compensate. Full-length spine X-ray images are required.

It explains the overall compensation relationship between the cervical and thoracolumbar deformities and can well explain the severe deformity of the cervical spine, that is, rigid or fixed deformity. However, this classification method did not include the resilience of patients with flexible-type CD as in the classification by Hanjo Kim et al., and the parameters used for this classification system were still not unique to patients with cervical deformity; thus, it was mostly based on the experience of experts.

Structured Treatment Algorithm to aid in the Decision-Making Process

The classification methods described above can describe each type of deformity; however, they appear insufficient to include all complex cervical deformities. These classification methods alone are not sufficient to provide a comprehensive explanation that establishes systematic classification and treatment scope.

CDs are mostly classified according to the rigidity of the deformity, and in clinical setting, they are simply divided into flexible and rigid types depending on whether passive correction was performed, with the patient lying down on the bed in the supine position for 5 minutes (Fig. 7).

The author would like to distinguish between flexible and rigid types according to the characteristics of the deformity and propose a structured treatment algorithm that can easily analyze the overall CD and aid in the decision-making process for the successful treatment of CDs (Fig. 8). According to this algorithm, the flexible type is classified into focal deformity, flat neck deformity, and cervicothoracic deformity according to the degree of ability to recover CL as much as T1S in flexion–extension dynamic images. Focal deformity is balanced within the cervical spine. Therefore, the scope of surgical treatment is determined within the cervical spine. Since CL cannot be recovered as much as T1S in flat neck deformity, the scope of surgical treatment is expanded from C2 to T1–3. If T1S is >30°, the CL is <30°, and deformity of not only the cervical spine but also the thoracic spine is present; thus, the scope of compensation should be relatively large and the scope of surgical treatment should be expanded to the point where the LIV is located in the mid-lower T spine.

On the contrary, in the rigid type (or fixed), it depends on whether the deformity is limited to the cervical spine (type 1: low T1S <30°, high C2 tilt >20°) or whether the deformity extends beyond the cervical spine to the thoracolumbar spine (type 2: high T1S >30°, low C2 tilt <20°), and the type in which the deformity extends beyond the thoracolumbar spine and includes the cervical spine and the cervical spine cannot compensate for the deformation of the thoracolumbar spine is classified as type 3 (high T1S >30°, high C2 tilt >20°). This can help in effectively understanding the nature and degree of deformity. Depending on where the location of deformity is limited, the scope of treatment is determined accordingly. Although this algorithm may quickly and easily determine the nature and treatment range of complex cervical deformities, it was proposed based on recently known classification systems, and its usefulness must be confirmed through more clinical applications.

Case Examples

Based on the above parameters and classification methods needed in analyzing and evaluating patients with cervical deformity, the following examples are provided on how to apply them to patients:

Case 1 (Fig. 9A–D)

An 84-year-old female patient visited the hospital with neck pain, restricted neck motion, mild numbness in the right arm (C4, 5, 6, 7, and 8 dermatomes), limited horizontal vision, and difficulty raising her head. She cannot raise her head and maintain it for >5 minutes and complained of severe pain in the neck area and restricted movement. In her medical history, she had undergone hip and shoulder arthroplasty on the right side and bilateral knee arthroplasty. The motor strength of her bilateral limbs was normal; however, she walked in with her cane, supported by her daughter. Radiographic findings including key parameters were as follows: CL=−19.7°, C2S=49.6°, T1S=48.1°, C2–7 SVA=73.9 mm, CBVA=14.7°, TK=43.5°, LL=43.9°, SS=13.2°, PT=31.0°, PI=44.2°, CTPA=11.9°, and TPA=29.7°. The bone mineral density was −2.9.

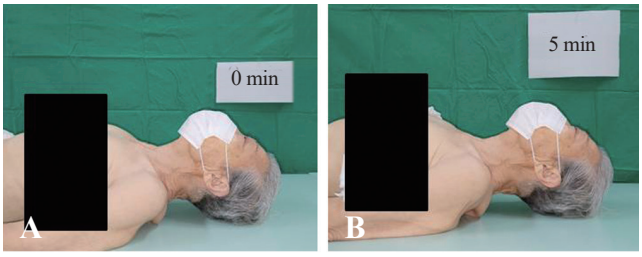


Fig. 7. (A, B) Photos showing the deformity are flexible or rigid type. Place the patient on the bed for 5 minutes and evaluate whether the cervical spine deformity can be recovered. Written informed consent for the publication of this image was obtained from the patient.

According to the Ames-ISSG classification, the patient was classified as having the CT type, modifier 2, 2, 2, 1, N, 0, +, ++, and according to the Koller-CSRS Europe classification, she had type B (cervical kyphosis, cervicothoracic kyphosis), a global imbalanced type. According to the Hanjo Kim classification, she was categorized into type 3, which might require a 3CO and surgery to place the LIV in the mid-lower T-spine. According to the Protopsaltis classification, she had type 3, showing high C2S and high T1S, and this type includes both thoracolumbar and cervical deformities; thus, surgery involving all areas should be considered. Existing classification methods can help establish the main deformity area and treatment range for this patient; however, judging which classification method is better or more advisable to apply in the analysis or determine the treatment range for patients with complex deformities is not easy. Systematically classifying the patient's defor-

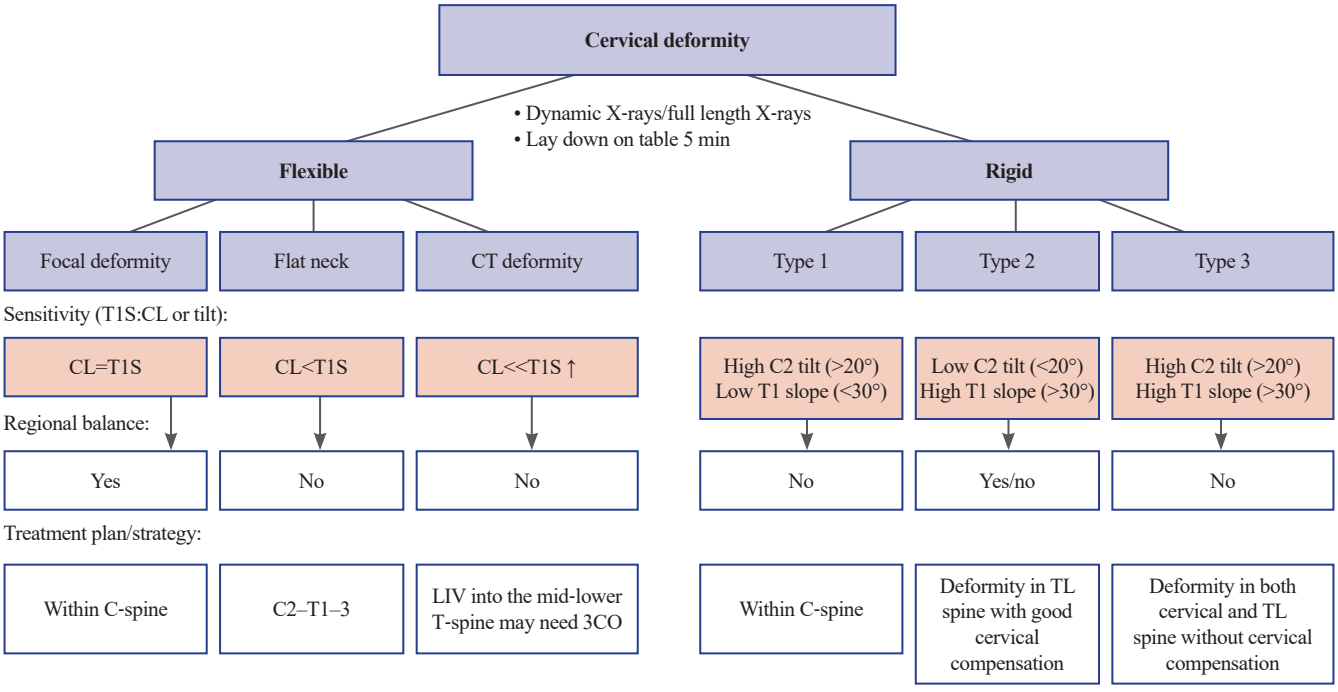
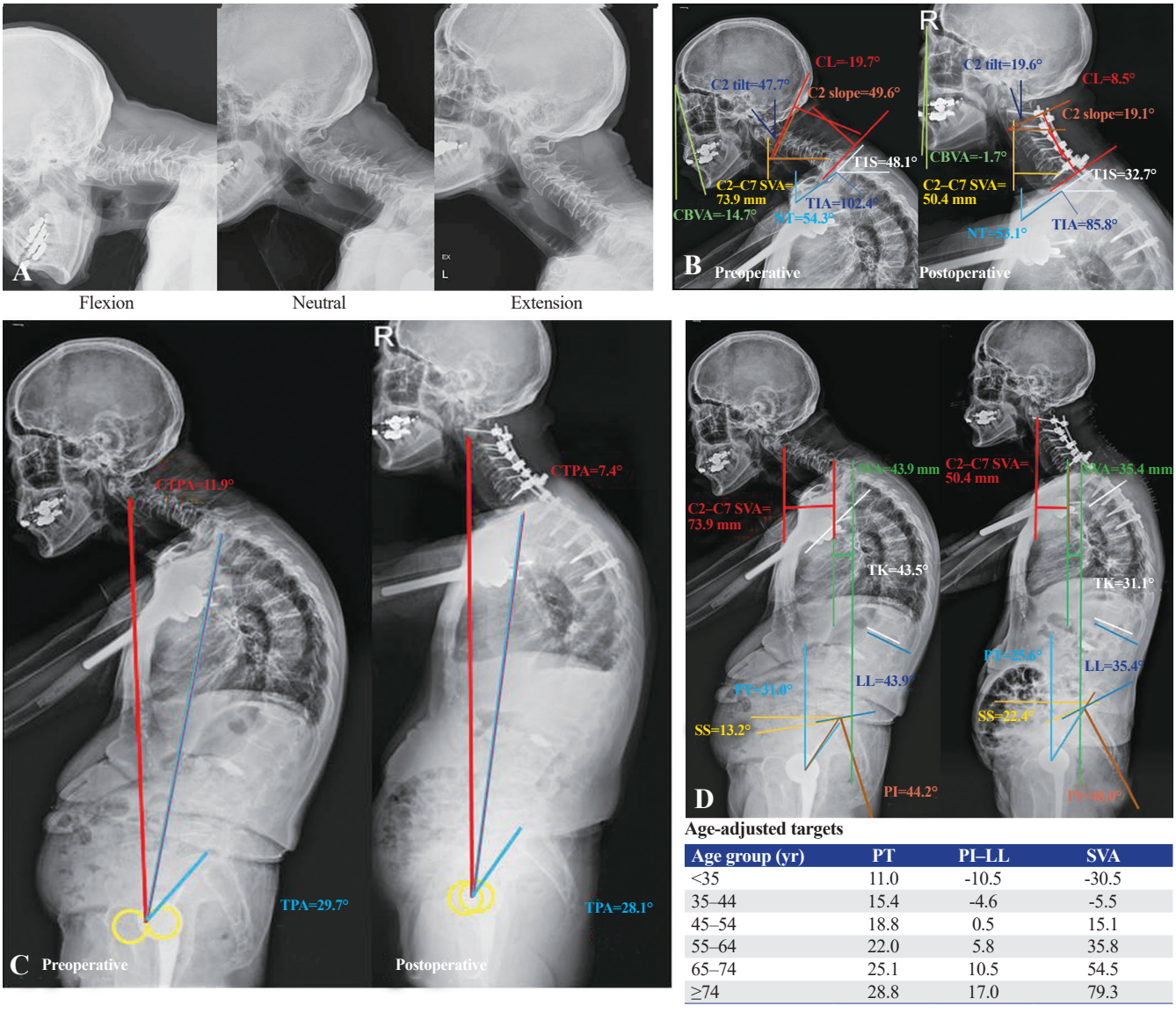


Fig. 8. The illustration explains a structured treatment algorithm of cervical spine deformities which helps to aid decision-making process for the successful treatment according to their characteristics of deformity. CT, cervicothoracic; CL, cervical lordosis; LIV, lower instrumented vertebra; TL, thoracolumbar; 3CO, three-column osteotomy.

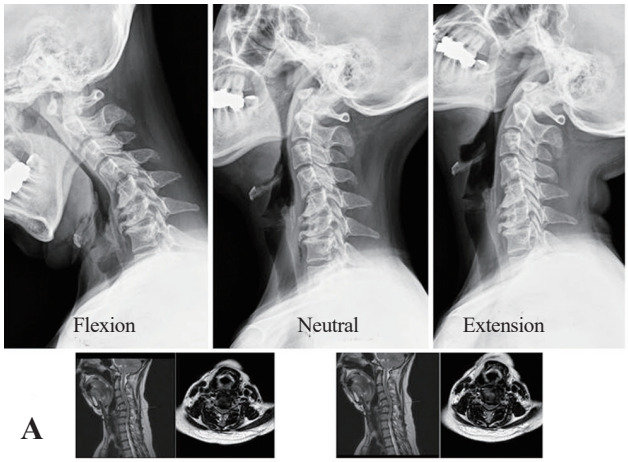


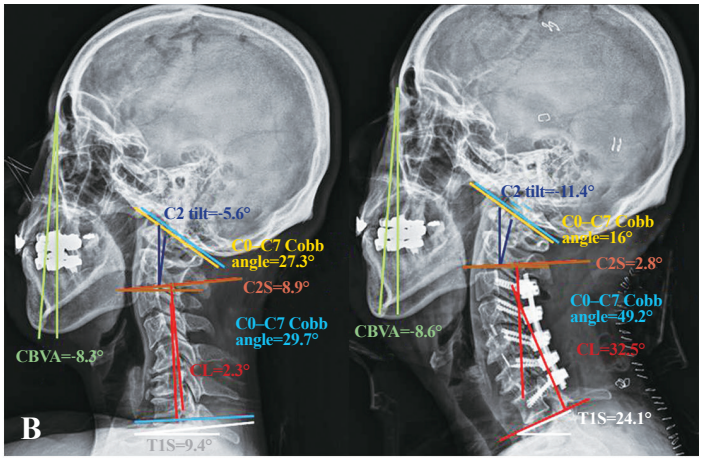
Age-adjusted targets

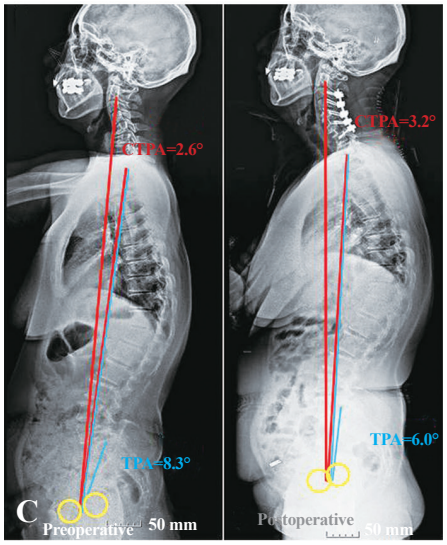
Age group (yr)	PT	PI–LL	SVA
<35	11.0	-10.5	-30.5
35–44	15.4	-4.6	-5.5
45–54	18.8	0.5	15.1
55–64	22.0	5.8	35.8
65–74	25.1	10.5	54.5
≥74	28.8	17.0	79.3

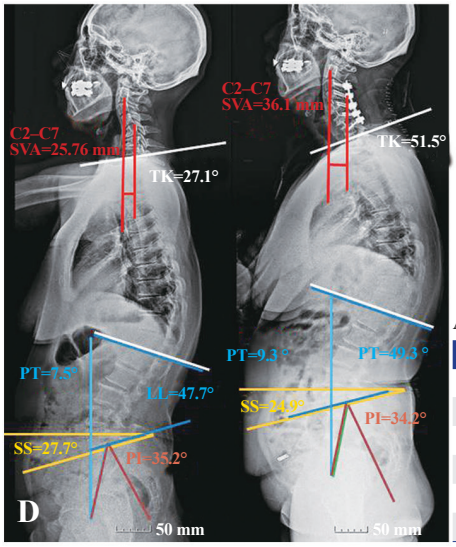
Fig. 9. Radiographic findings and parameters of an 84-year-old female patient. **(A)** Flexion, neutral, extension state of cervical spine on lateral X-rays of an 84-year-old female patient. The patient has kyphotic curvature which is not reducible during extension. **(B)** Radiographic findings showing the change of key parameters at cervical spine level before and after surgery. Preoperative parameters were measured as follows: CL=-19.7°, C2S=49.6°, T1S=48.1°, C2–7 SVA=73.9 mm, and CBVA=14.7°. After surgery, parameters were corrected to CL=8.5°, C2S=19.1°, T1S=32.7°, C2–7 SVA=50.4 mm, and CBVA=-1.7°. CL, cervical lordosis; C2S, C2 slope; T1S, T1 slope; SVA, sagittal vertical axis; CBVA, chin–brow–vertical angle. **(C)** Radiographic findings showing the change of key parameters at spine and pelvis area before and after surgery. Preoperative parameters were measured as follows: CTPA=11.9°, TPA=29.7°. After surgery, parameters were corrected to CTPA=7.4°, TPA=28.1°. CTPA, cervicothoracic pelvic angle; TPA, thoracic pelvic angle. **(D)** Radiographic findings showing the change of key parameters at global spine and pelvis before and after surgery. Preoperative parameters were measured as follows: TK=43.5°, LL=43.9°, SS=13.2°, PT=31.0°, and PI=44.2°. After surgery, parameters were corrected to TK=31.1°, LL=35.4°, SS=22.4°, PT=25.6°, and PI=48.0°. TK, thoracic kyphosis; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence.

mity according to whether it is a flexible type or a rigid (or fixed) type, and in what situations should Hanjo Kim classification, which takes into account the recovery ability of the curve during extension, be applied is also difficult. In addition, whether flexion–extension dynamic rays are absolutely essential or what classification is advisable for patients who cannot undergo flexion–extension X-ray imaging is also unclear. In this case, the treatment algorithm proposed can be applied (Fig. 8). First, place the patient on the bed for 5 minutes and evaluate whether the CD can be recovered. This patient was classified as having a rigid type because the deformity did not recover during extension, and the original shape was maintained. Then, this patient was further categorized as having type 3 because she had high C2S and high T1S. This means that both thoracolumbar and cervical deformities must be corrected. After total laminectomy at T1, partial laminectomy at C7









Age-adjusted targets

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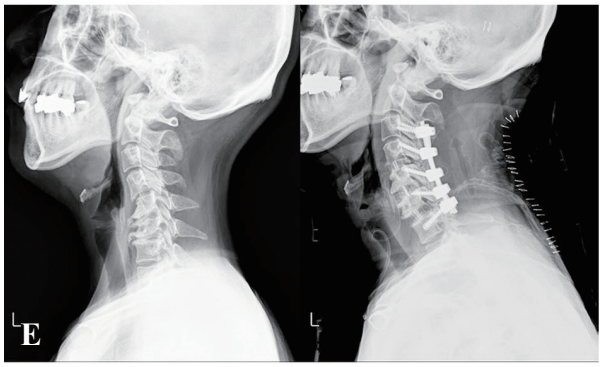
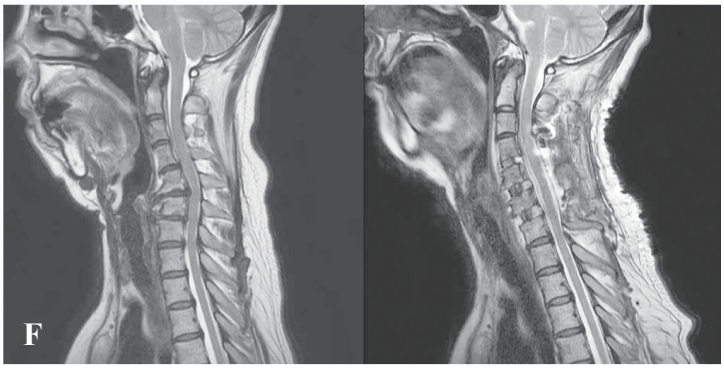
55–64	22.0	5.8	35.8
65–74	25.1	10.5	54.5
≥74	28.8	17.0	79.3



Preoperative Postoperative



Preoperative Postoperative

Fig. 10. Radiographic findings and parameters of a 41-year-old female patient. **(A)** Flexion, neutral, extension state of cervical spine on lateral X-rays and magnetic resonance imaging (MRI) of a 41-year-old female patient. The patient has kyphotic curvature on neutral position but the curve is recovered during extension. **(B)** Radiographic findings showing the change of key parameters at cervical spine level before and after surgery. Preoperative parameters were measured as follows: CL=2.3°, C2S=8.9°, T1S=9.4°, C2–7 SVA=25.76 mm, and CBVA=-8.3°, After surgery, parameters were corrected to CL=32.5°, C2S=2.8°, T1S=24.1°, C2–7 SVA =36.1 mm, and CBVA=-8.6°. CL, cervical lordosis; C2S, C2 slope; T1S, T1 slope; SVA, sagittal vertical axis, CBVA, chin–brow–vertical angle. **(C)** Radiographic findings showing the change of key parameters at spine and pelvis area before and after surgery. Preoperative parameters were measured as follows: CTPA=2.6° and TPA=8.3°. After surgery, parameters were corrected to CTPA=3.2° and TPA=6°. CTPA, cervicothoracic pelvic angle; TPA, thoracic pelvic angle. **(D)** Radiographic findings showing the change of key parameters at global spine and pelvis before and after surgery. Preoperative parameters were measured as follows: TK=27.1°, LL=47.7°, SS=27.7°, PT=7.5°, and PI=35.2°. After surgery, parameters were corrected to TK=51.5°, LL=49.3°, SS=24.9°, PT=9.3°, and PI=34.2°. TK, thoracic kyphosis; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence. **(E)** The change of alignment before and after surgery on lateral X-rays. **(F)** The change of MRI findings before and after surgery. After surgery, the canal is well relieved and recovered its size and shape.

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and T2, and 3CO at T1, posterior instrumentation and fusion was performed at C2–T6, this patient showed CL=8.5°, C2S=19.1°, T1S=32.7°, C2–7 SVA=50.4 mm, CBVA=−1.7°, TK=31.1°, and LL=35.4°. It was also corrected to SS=22.4°, PT=25.6°, PI=48.0°, CTPA=7.4°, and TPA=28.1°.

Case 2 (Fig. 10A–E)

A 41-year-old female patient visited the hospital with neck pain, neck motion limitations, and limb muscle weakness. She had difficulty extending her neck, and pain, particularly in the lower part of her neck, was severe, so she had difficulty maintaining her daily routine. She complained of symptoms of myelopathy and showed Hoffman sign +, grip and release 9–10/10 seconds, finger flexor -/+, and inverted radial reflex -/+.

Radiographic findings, including key parameters, were as follows: CL=2.3°, C2S=8.9°, T1S=9.4°, C2–7 SVA=25.76 mm, CBVA=−8.3°, TK=27.1°, LL=47.7°, SS=27.7°, PT=7.5°, PI=35.2°, CTPA=2.6°, TPA=8.3°, and mJOA=13.

Preoperative flexion/extension lateral X-ray images showed that the curve of the cervical spine was nearly completely recovered during extension, although it was not complete. However, most recovery during extension occurred at C0–2, and the lesion area still had limitations in recovery. Magnetic resonance imaging also showed stenosis of the lower cervical spine and spinal cord compression. Because T1S and TPA were within the normal range, no particular problem with the relationship between the cervical region and other adjacent thoracolumbar spine and pelvis was found. According to the Ames-ISSG classification, she was classified as having type C, modifier 0, 1, 0, 2, N, +, 0, 0. According to the Koller-CSRS Europe classification, she had type C (CL maintained/cervicothoracic kyphosis, global imbalanced type). According to the Hanjo Kim classification, she was categorized as having type 2 focal deformity, which recovers to a similar degree during extension and flexion and requires deformity treatment limited to the cervical spine. However, applying the Protopsaltis classification to this patient was challenging. If this patient has a type that shows low C2S and low T1S because both C2S and T1S are in the normal range, this case does not belong to any type of this classification. According to the proposed algorithm (Fig. 8), she certainly had a flexible type that restored the original cervical curve when laid down in bed for 5 minutes and was considered a type 1 focal deformity, which maintained regional balance within the cervical spine; thus, treatment limited to the cervical spine was required. After surgery, the following parameters were obtained: CL=32.5°, C2S=2.8°, T1S=24.1°, C2–7 SVA=36.1 mm, CBVA=−8.6°, TK=51.5°, LL=49.3°, SS=24.9°, PT=9.3°, PI=34.2°, CTPA=3.2°, TPA=6°, and mJOA score=16.

Conclusions

In CD, the cervical spine deviates from its normal alignment and loses the ability to maintain horizontal vision and performance of normal functions of the cervical spine through interaction with other thoracolumbar spine and the pelvis. Thus, efforts are required to evaluate complex CD using various parameters and to treat it effectively by appropriately applying the latest known classification systems. In addition, a structured treatment algorithm based on recently known classification systems aids in the decision-making process for the treatment of complex CDs.

Key Points

- Cervical deformity can have a significant impact on health related quality of life.
- The first generation International Spine Study Group cervical deformity classifications appear to be a good start as a guide to help define treatment goals, however, they are so diverse and complex that it has been pointed out as a problem which classification method should be used appropriately according to the characteristics of cervical deformity.
- The treatment algorithm proposed here can help effectively understand cervical deformity and determine treatment plans depending on the nature and degree of deformity.
- Certainly, this is evolving, as we learned more about cervical deformity, other parameters may be added and there may be further refinement of the goals for those measures.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Author Contributions

All the work for the preparation of this review article was done by Seok Woo Kim.

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