European Spine Journal (2021) 30:1670–1680
https://doi.org/10.1007/s00586-021-06751-1

ORIGINAL ARTICLE

A new nomenclature system for the surgical treatment of cervical spine deformity, developing, and validation of SOF system

Jae Taek Hong[1] · Heiko Koller[2] · Kuniyoshi Abumi[3] · Wen Yuan[4] · Asdrubal Falavigna[5] · Ho Jin Lee[6] · Jong Beom Lee[7] · Jean-Charles Le Huec[8] · Jong-Hyeok Park[9] · Il Sup Kim[6]

Received: 19 May 2020 / Revised: 8 December 2020 / Accepted: 23 January 2021 / Published online: 6 February 2021

Abstract

Purpose To develop and assess the reliability of new nomenclature system that systematically organizes osteotomy techniques and briefly describes the surgical approach, the surgical sequence, and the fixation technique for cervical spine deformity (CSD).

Methods We developed a new classification system (SOF system) for CSD surgery that describes the sequence of surgical approach (S), the grade of osteotomy (O), and the information of fixation (F) using alphanumeric codes.

Twenty CSD osteotomies (8 anterior osteotomies, 12 posterior osteotomies) were included in this study to evaluate the inter- and intra-observer agreement based on operation records.

Six observers performed independent evaluations of the operation records in random order. Each observer described 20 CSD surgeries using the SOF system twice (> 30 days between assessments) based on operation records to validate SOF system.

Results Overall agreement (among all six observers at the initial assessment) on the anterior and posterior osteotomy was ICC = 0.96 and ICC = 0.91, respectively. Overall agreement (repeat observations after at least 30 days) on the anterior and posterior osteotomy was ICC = 0.96 and ICC = 0.91, respectively.

This data showed that both inter- and intra-observer agreement revealed ‘excellent’.

Conclusion This study introduces the SOF system of the CSD surgery to understand the surgical sequence, the type of osteotomy and the fixation techniques. The investigation of the inter- and intra-observer agreement revealed ‘excellent agreement’ for both anterior and posterior osteotomies.

Thus, SOF system can provide a consistent description of the various CSD surgeries and its use will provide a common frame for CSD surgery and help communicate between surgeons.

Keywords Cervical spine · Deformity · Surgery · Nomenclature · Validation

✉ Jae Taek Hong
jatagi15@gmail.com

1 Department of Neurosurgery, Eunpyeong St. Mary's Hospital, The Catholic University of Korea, Seoul, Korea

2 Department of Neurosurgery, Technical University of Munich, Munich, Germany

3 Department of Orthopedic Surgery, Sapporo Orthopedic Hospital, Sapporo, Japan

4 Department of Orthopedic Surgery, Changzheng Hospital, Second Military Medical University, Shanghai, China

5 Department of Neurosurgery, University of Caxias Do Sul, Caxias Do Sul, RS, Brazil

6 Department of Neurosurgery, St. Vincent's Hospital, The Catholic University of Korea, Suwon, Korea

7 Department of Neurosurgery, Chungbuk National University Hospital, Cheongju, Korea

8 Department of Orthopedic Surgery, Bordeaux University Hospital, Bordeaux, France

9 Department of Neurosurgery, Incheon St. Mary's Hospital, The Catholic University of Korea, Incheon, Korea

Introduction

Cervical spine deformities (CSD) can develop secondary to multiple causes such as degenerative disease, iatrogenic deformity, inflammatory disorders, and congenital malformation which may alter the normal biomechanics of the spine [1, 2]. The weight bearing axis is translated anteriorly as the disk spaces decreased in height, leading to tensile load in the posterior elements and causing debilitating fatigue muscle pain [3–5]. Patients often present with debilitating conditions ranging from generalized decreased quality of life to quadriplegia [6–8].

Recently, understanding of the cervical sagittal alignment and surgical methods has been developed [7, 9–11]. So, surgical treatment of CSD becomes a subject of interest. However, surgical correction of CSD can be challenging because the target of surgical correction is adjacent to the critical neurovascular structures [3, 10, 12–17]. Thus, the postoperative complications have been reported to be relatively high and the number of studies on CSD is far inferior to those of thoracolumbar deformity [18, 19].

Although there have been recent advances in standardized classification and nomenclature system for osteotomy technique to manage adult thoracolumbar deformity, there is no classification system for CSD surgeries that systematically organizes the anterior and posterior cervical osteotomy techniques, respectively[20–22]. Moreover, there is lack of standardization regarding surgical approach and surgical technique for CSD.

Standardized surgical techniques and nomenclature system for CSD are essential for effective communication between researchers and effective evaluation of the surgical results.

So, the purpose of this study was to develop a unified nomenclature system for systematizing osteotomy techniques that can briefly describe the surgical approach, the grade of osteotomy, the sequence of CSD surgeries, and the information of fixation.

Methods

Description of the new nomenclature and classification system

This new nomenclature system of CSD surgeries was designed to be simple, graduated, anatomically based, and surgically oriented.

SOF system is a notation system that describes the sequence of surgical approach, the grade of osteotomy, the sequence of CSD surgeries, and the information of fixation techniques using alphanumeric codes. All CSD surgeries using the SOF classification are given an APF description.

- **S** describes the sequence of surgical approach. Description sequence of **A** and **P** is the order of surgical approach. If the anterior surgery is performed first, **A** is described first. If posterior surgery is performed first, **P** is first written.
- **O** describes the grades and type of osteotomy technique**.** Anterior osteotomies are divided into four grades. Grades of osteotomies correspond to the extent of bony resection and increasing degree of destabilizing potential. Posterior osteotomies are divided into six grades.
    - **A** (0, 1, 2, 3, 4): **A** stands for anterior surgery and describes the grades of anterior osteotomy techniques. Anterior osteotomies are divided into four grades (Fig. 1, Table 1). **A**0 means that anterior approach is not performed for the CSD correction.
    - **P** (0, 1, 2, 3, 4, 5, 6): **P** stands for posterior surgery and describes the grades of posterior osteotomy techniques. Posterior osteotomies are divided into six grades proposed by Schwab et al. for the treatment of thoracolumbar deformity (Fig. 2, Table 2). **P**0 means that posterior approach is not performed for the CSD correction. Although vertebral column resection (VCR) may not be an appropriate procedure for the cervical spine because of the vertebral artery and functioning nerve roots, sometimes upper thoracic VCR is indicated for the treatment of cervicothoracic deformity. Thus, it was included as Grade 6 posterior osteotomy for CSD.

- **F**: **F** stands for fixation technique and describes the level and methods of fixation. Fixation techniques are divided into three methods (Table 3).

  In situ fixation (IF) could be used if the CSD is reducible with positional change. Anterior in situ fixation (AIF) or posterior in situ fixation (PIF) can be used.

  Compressive fixation (CF) could be used when osteotomy is needed to realign the spine. If posterior compressive fixation (PCF) is necessary after posterior column shortening osteotomies (SPO, PSO, and VCR), sequential compression against the screws' head should be performed.

  Distractive fixation (DF) could be useful, especially for focal deformity. Anterior distractive fixation (ADF) or posterior distractive fixation (PDF) can be used depending on the surgical approach and the apex of the deformity.

  If the surgical approach is changed, it is expressed as "/ ". In the same approach, the expression of the surgical method appears by inserting ";" between each different

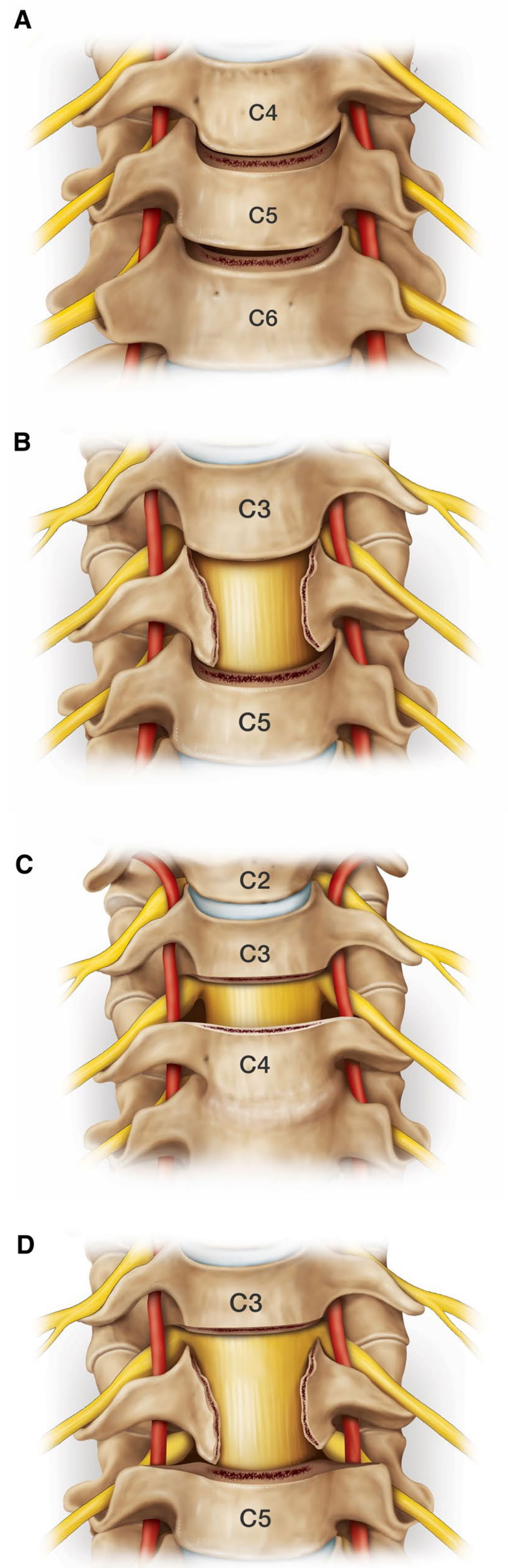

Fig. 1 Illustrations show four different grades of anterior osteotomies ▸ (**A**) Grade 1 anterior osteotomy (A1), discectomy with or without partial uncovertebral joint resection (**B**) Grade 2 anterior osteotomy (A2), partial or complete corpectomy (**C**) Grade 3 anterior osteotomy (A3), complete uncovertebral joint resection to the transverse foramen (TF) (**D**) Grade 4 anterior osteotomy (A4), complete corpectomy with adjacent uncovertebral joint resection to the TF

surgical method. Level of surgery is described in parentheses.

Validation of the new nomenclature system for cervical osteotomies

Six observers of variable experience performed independent evaluations of the operation records in random order. Each observer described 20 CSD osteotomies (8 anterior osteotomies, 12 posterior osteotomies) using the SOF system twice (> 30 days between assessments) based on operation records.

Statistical analysis

Outcomes were measured using intraclass correlation coefficient (ICC), which summarizes agreement within or between observers in comparison with the probability of agreement by chance.

For ordinal data (anterior and posterior osteotomy grade), absolute agreement ICC was used, analysis of variance was performed using a two-way random effects model of individual values. The interpretation of test values was according to the guidance provided by Koo and Li who described values below 0.50 as 'poor agreement', 0.5–0.75 as 'moderate agreement', 0.75–0.90 as 'good agreement', and above 0.90 as 'excellent agreement' [23].

Results

Observer agreement

Inter-observer agreement

Overall agreement (among all six observers at the initial assessment) on the anterior osteotomy and posterior osteotomy was ICC = 0.914 (95% CI:0.770–0.980) and ICC = 0.990(95% CI:0.977–0.997), respectively.

Table 1 Anterior osteotomy classification

Grades	Description
A1	Discectomy and partial uncovertebral joint resection
A2	Partial or complete corpectomy
A3	Complete uncovertebral joint resection to the transverse foramen
A4	Complete corpectomy with adjacent uncovertebral joint resection to the TF

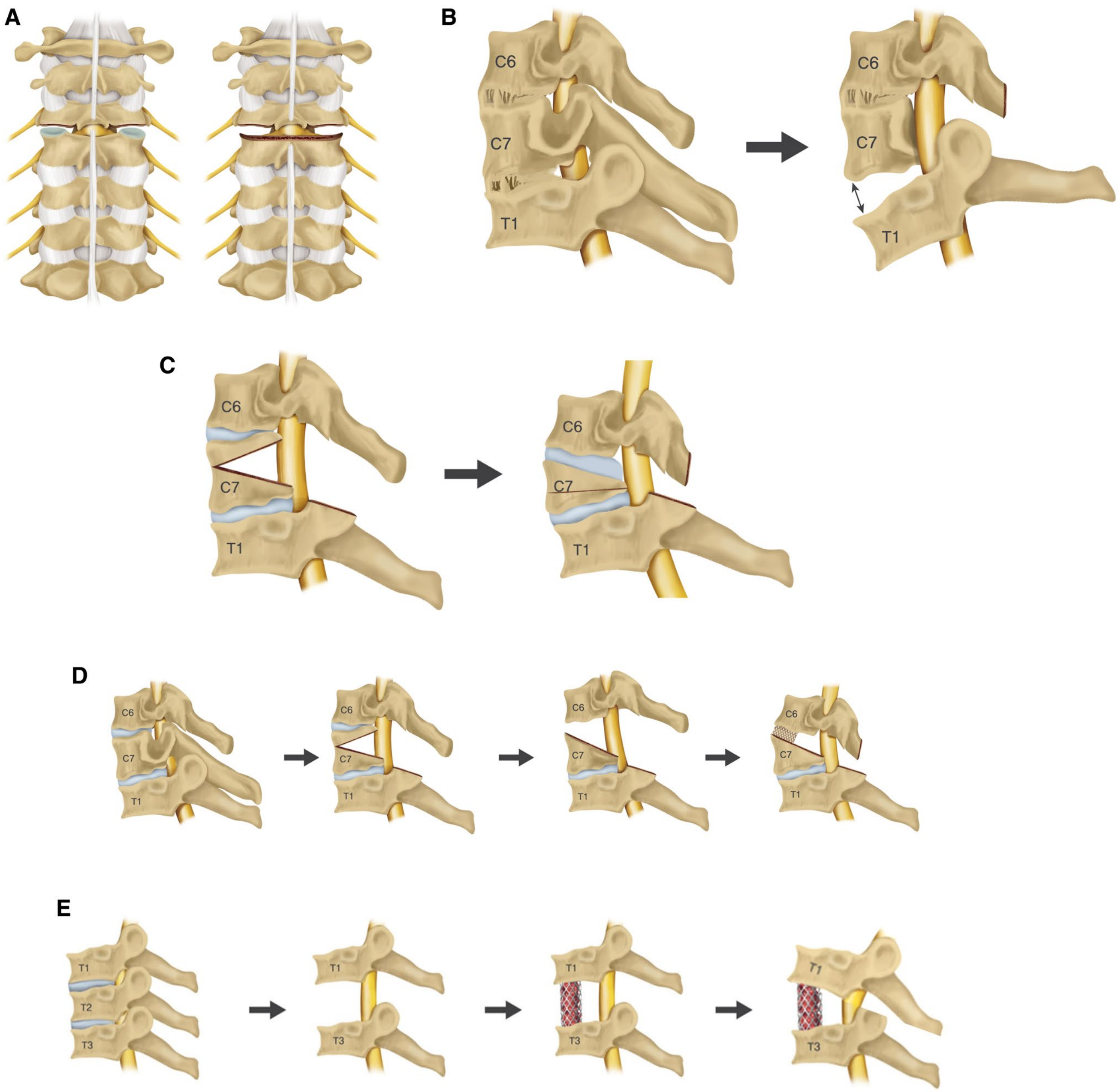

Fig. 2 Illustrations show six different grades of posterior osteotomies (**A**) Grade 1 posterior osteotomy (P1), partial facet joint resection; Grade 2 posterior osteotomy (P2), complete facet joint resection (eg. SPO) (**B**) Grade 3 posterior osteotomy (P3), opening wedge osteotomy (OWO) (**C**) Grade 4 posterior osteotomy (P4), closing wedge osteotomy (CWO) (**D**) Grade 5 posterior osteotomy (P5), pedicle, partial body and disk resection (Trans-discal PSO) (**E**) Grade 6 posterior osteotomy (P6), vertebral column resection (VCR)

Table 2 Posterior osteotomy classification

Grades	Description
P1	Partial facet joint resection
P2	Complete facet joint resection (eg. SPO)
P3	Opening wedge osteotomy (OWO); resection of laminae, spinous process, and facets with subsequent osteoclastic fracture and formation of an anterior wedge in the anterior column
P4	Closing wedge osteotomy (CWO); pedicle and partial body resection (eg. PSO)
P5	Pedicle, partial body and disk resection (Trans-discal PSO)
P6	Vertebral column resection (VCR)

Table 3 Methods of fixation

Fixation methods	Description
IF	In situ fixation
CF	Compressive fixation
DF	Distractive fixation

(AIF; anterior in situ fixation, PIF; posterior in situ fixation, PCF; posterior compressive fixation, PDF; posterior distractive fixation)

Intra-observer agreement

Overall agreement (repeat observations after at least 15 days) on the anterior osteotomy and posterior osteotomy was ICC = 0.925 (95% CI:0.867–0.958) and ICC = 0.987 (95% CI:0.979–0.992), respectively.

Cases examples

SOF classification system is not designed to describe the surgical indication, efficacy, prognosis or optimal surgical approach for each different types of CSD.

Instead, this new osteotomy classification is an anatomical and technical description system to understand the sequence of the surgical correction, the grade of osteotomy and the fixation techniques.

New system can be applied on all kinds of CSD. Through the following case examples, we can see how to describe various types of CSD surgery using the SOF classification system.

Case example 1

A 39-year-old woman presented with chronic neck pain and limited neck motion due to old fracture of C5-6. Imaging studies showed semirigid focal cervical kyphosis with canal impingement. Authors corrected her semirigid focal kyphosis (Fig. 3A, B) with C5-6 anterior corpectomy and instrumentation, it can be expressed as "A2 (C5–6); ADF (C4–7)/P0".

Case example 2

A 69-year-old man presented with neck pain, severe occipital headache and abnormal neck tilt. Imaging demonstrated an asymmetrical C1-2 joint mutilation and C2 root impingement (Fig. 4).

Posterior only surgery was performed. Unilateral C1-2 facet joint distraction was necessary to correct neck tilt caused by the rheumatoid arthritis and posterior C1-2 instrumentation was performed. These procedures can be expressed as follows: "A0/P1 (C1-2); PDF (C1-2)".

Case example 3

A 53-year-old woman presented with a history of progressive cervical axial pain, hand clumsiness, and difficulty with a horizontal gaze. She had been diagnosed with cerebral palsy. Plain radiographs of the cervical spine showed a semirigid cervical kyphosis with multilevel cervical spondylotic stenosis. Single staged 540-degree surgery was performed (Fig. 5). We initially performed posterior column osteotomy and instrumentation at C3–6 level to release posterior column. And then, multilevel anterior cervical discectomy and fusion was performed from C3 to C7. Finally, posterior compressive fixation was done for posterior column shortening from C3 to C7. The procedure and the extent of osteotomy and the extent of fixation can be described as "P2 (C3–6) / A1 (C3–7); ADF (C6–7) / PCF (C3–7)".

Case example 4

A 37-year-old man presented with a history of progressive cervical axial pain, refractory to analgesics and opioids, difficulty in swallowing, and inability to walk with a horizontal

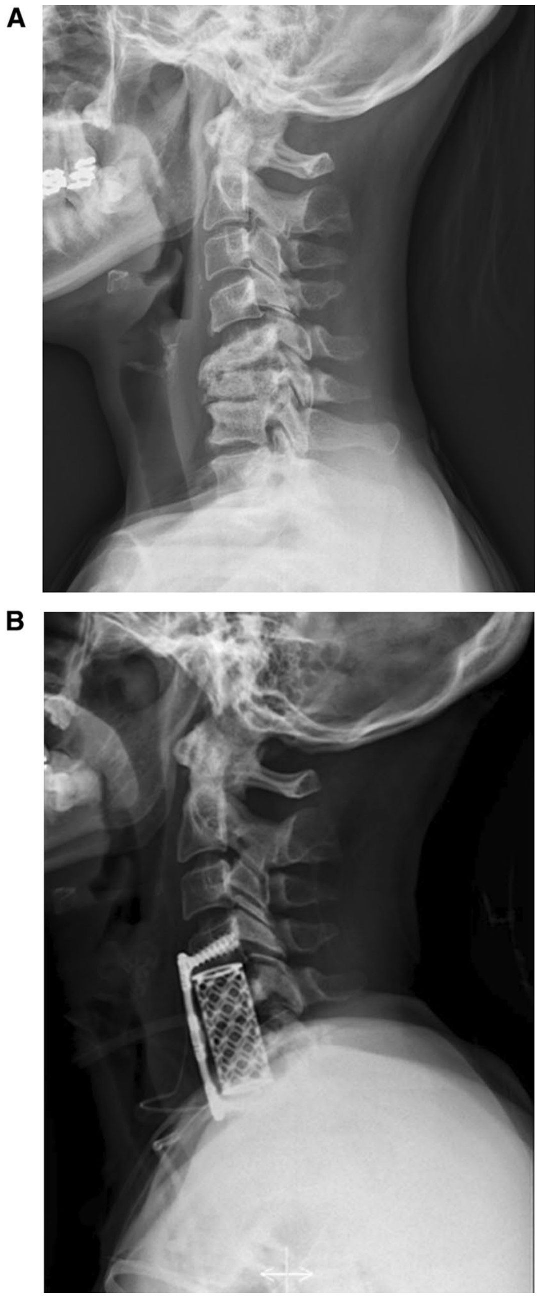

Fig. 3 (**A**) Lateral preoperative radiograph demonstrating focal kyphosis at C5-6 level. (**B**) Postoperative radiograph shows corrected semirigid focal kyphosis with C56 anterior corpectomy, it can be expressed as "A2 (C5-6); ADF (C4-7)/P0"

gaze. He had been diagnosed with ankylosing spondylitis (AS) in another hospital. Physical examination evidenced the inability to move his neck with limitation of all movements (flexion, extension, and lateral bending). He had no neurological deficits or reflex abnormalities. Plain radiographs of the cervical spine showed a fixed cervical kyphosis with evident bone fusion in the anterior and posterior elements of his spine (Fig. 6). A cervical MRI was performed, and no spinal cord compression was visualized.

When C7 pedicle subtraction osteotomy (PSO) was needed in the case of severe ankylosing spondylitis (Fig. 6), it can be expressed as "A0/P4 (C7); PCF (C2–T3)".

Discussion

The primary goals of CSD surgeries are to restore the sagittal alignment of the neck, improve horizontal gaze, relieve nerve elements, and improve neck pain and overall functional outcomes, which are like the goals of thoracolumbar deformity surgery [12, 18, 24].

Although CSD is becoming increasingly recognized and effective surgical correction has received much attention in recent years, assessment and decision making of CSD are still challenging [2, 9, 25, 26]. It is not only because the pathologies are heterogeneous, but also surgical strategies and classification of the CSD is not yet fully established. Besides, a relatively lower incidence of CSD could be an obstacle to advance CSD surgery.

Despite considerable progress in classification and recommended strategies for treating thoracolumbar deformities, advances of CSD have lagged comparatively.

Treatment options and surgical correction are dependent on the specific characteristics of the spinal deformity and the level of deformity.

Most of the thoracolumbar spine deformities can be treated by posterior only surgery, so it could be simple to express the surgical grade of thoracolumbar deformity [20, 22]. However, CSD surgery has various approaches: anterior approach, posterior approach, simultaneous anterior–posterior approach, and 540-degree approach; because of the surrounding neurovascular structures, expressing the surgical grade of CSD surgery could be rather complicated [3, 14, 27, 28].

Recently, a classification system has been developed to standardize the description of cervical osteotomy types [21]. However, this system is rather complicated to remember because the anterior and the posterior osteotomy techniques are not separated. Moreover, it is impossible to describe the operation sequence and the fixation details together using this system.

The range of cervical osteotomy can be divided into several grades according to the amount of bony resection and destabilization in each approach. Also, spinal deformity surgery should express the scope of spinal fixation because it involves segmental fixation surgery.

Multicenter studies and a long study period are usually required to evaluate the treatment efficacy of rare diseases such as CSD.

Fig. 4 Preoperative radiograph (**A**) shows lateral neck tilt. Clinical photograph is showing abnormal neck tilt caused by craniovertebral malalignment. Preoperative CT reconstruction image (**C**) demonstrating severe joint mutilation at right side C1-2 joint (arrows). Intraoperative photograph (**D**) showing intraarticular graft insertion (white arrow) at right C1-2 joint space. It can be expressed as "A0/P1 (C1-2); PDF (C1-2)"

Standardized techniques and nomenclature systems are especially essential for rare disease entities to obtain consistent data and validate treatment effectiveness [29].

Therefore, it is necessary to have a standardized nomenclature system that can facilitate communication among researchers and effectively evaluate the surgical results of CSD surgery [22, 30].

So, the purpose of this study was to design and evaluate a new nomenclature system that can easily express the most important factors in the technique of cervical deformity surgery, such as the method of osteotomy, surgical approach, operation sequence, and detail of fixation.

We devised a new classification system (SOF system) for CSD surgeries similar to the TNM staging system for tumor evaluation. Before TNM classification, there were myriads of cancer staging systems. Nowadays, the cancer staging system has been standardized to the use of three basic parameters, the tumor (T), the node (N), and the distant metastasis or spread (M), constituting the so-called TNM staging system [31]. TNM classification has been accepted as a global standard to ensure that adequate treatment can be planned. An accurate prognosis can be given, and that there is a uniform system to evaluate the results of treatment [32, 33].

The proposed SOF system for CSD surgeries consists of three basic elements (S, O, F) like TNM staging system.

S, O, and F indicate the sequence of surgical approach (S), technique and grade of the osteotomy (O), and fixation techniques (F). The S, O, and F are referred to as "categories". The categories are then assigned to an anatomic/surgical technique group.

SOF classification system is not designed to describe the surgical indication, efficacy, prognosis, or optimal surgical approach for each different types of CSD.

Instead, this new classification system is an anatomical and technical description system for a detailed understanding of the surgical correction sequence, osteotomy grade, and fixation techniques. SOF system can be used as a standard classification system on all kinds of CSD surgery because its basic principles are; (1) applicability to all anatomic sites; (2) the capability to describe the surgical approach (anterior or posterior) and the sequence of surgical treatment (single

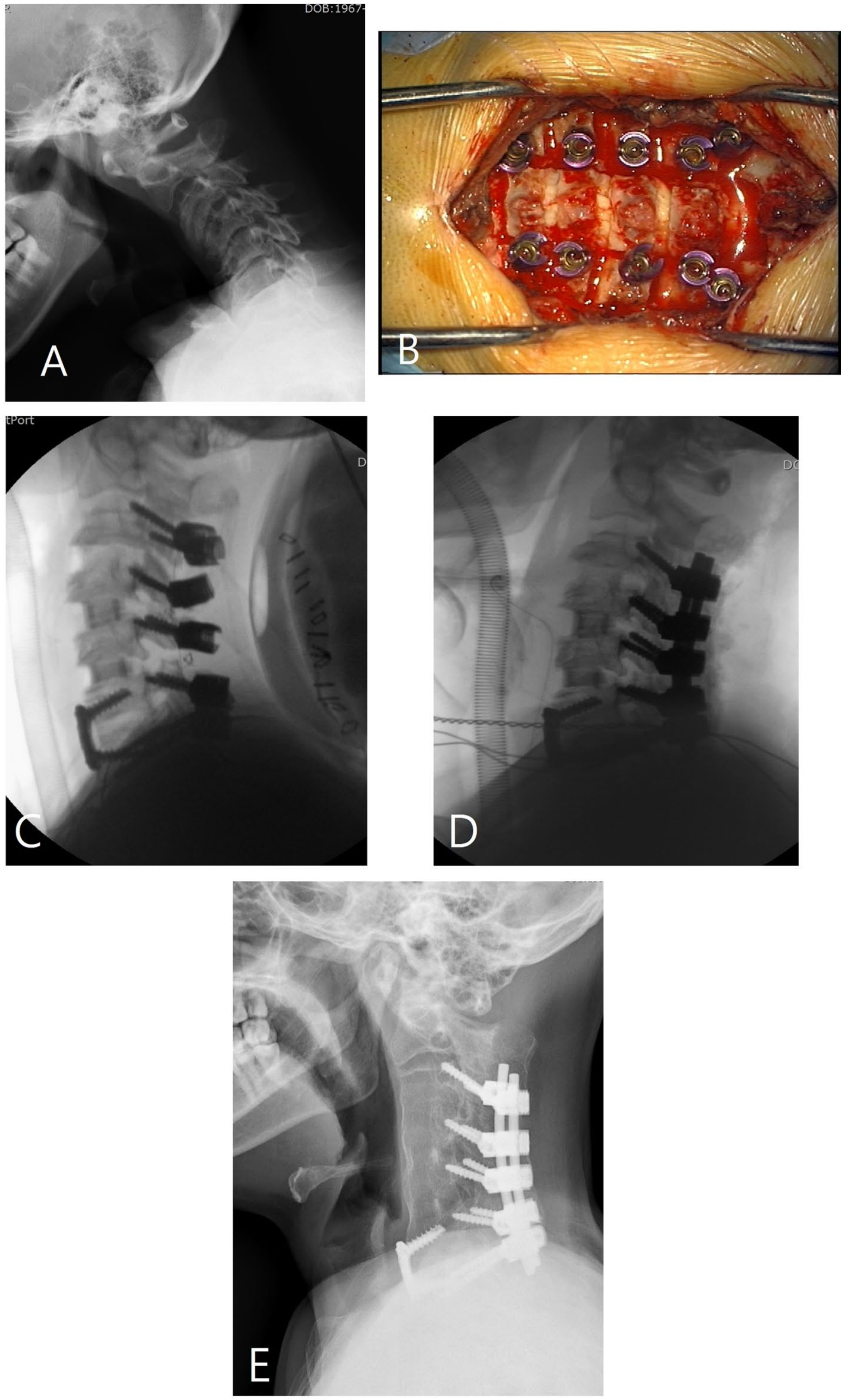

Fig. 5 **A** Lateral preoperative radiograph demonstrating severe degree cervical deformity and inability to maintain horizontal gaze. **B** Intraoperative photograph showing posterior column osteotomy and posterior instrumentation from C3 to C7. **C** Intraoperative radiograph demonstrating anterior discectomy and fusion from C3 to C7 and plate fixation at C67 level. **D** Final intraoperative radiograph demonstrating posterior column shortening and correction of cervical deformity. **E** Lateral postoperative radiograph demonstrating sound bone fusion of the cervical spine and improved sagittal balance of the neck 2 year after the surgery. These procedures can be expressed as "P2 (C3-6) / A1 (C3-7); ADF (C6-7) / PCF (C3-7)"

anterior, single posterior, combined approach or 540-degree surgery; A-P-A, P-A-P); (3) the capability to describe the different osteotomy grade, level, and method of fixation; (4) facilitate the exchange of information not only between surgeons, but also between treatment centers; and (5) contribute to the continuing investigation of CSD.

In the present study, we have demonstrated that both inter- and intra-observer agreement among six independent observers were "excellent."

This result shows that the SOF system could allow independent communication between other researchers, and it enables assessment by other groups and through other

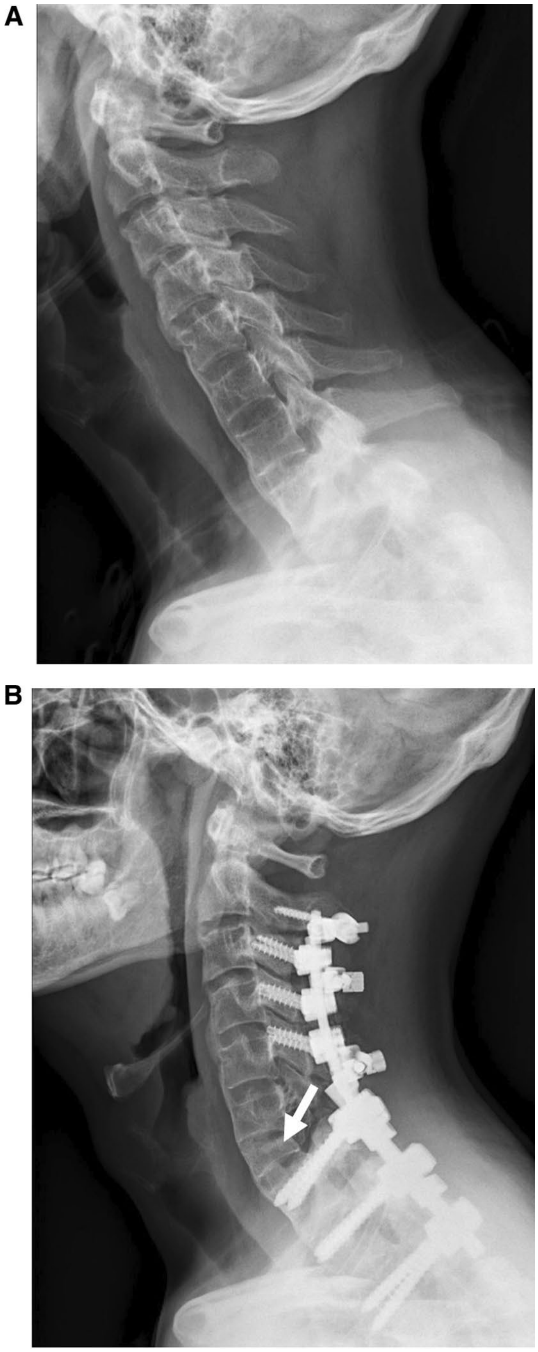

Fig. 6 Lateral preoperative (**A**) radiograph demonstrating fixed sagittal imbalance and ankylosing spondylitis in cervical spine. Postoperative (**B**) radiographs show C7 PSO (arrow), deformity correction, and instrumentation. Pedicle subtraction osteotomy at C7 level and posterior compressive fixation from C2-T3 can be expressed as “A0/P4 (C7); PCF (C2-T3)”

databases. TNM cancer staging helps health care providers and researchers exchange information about patients; it also gives them a common terminology for evaluating the results of clinical trials and comparing the results of different trials.

Although further multicenter prospective studies are needed to confirm the efficacy and consistency of this new nomenclature system, the SOF system could be the backbone of future advances for CSD surgery as the TNM staging system did for cancer treatment.

The proposed SOF classification system might not be the final version and several modifiers may be additionally needed. Further progress and revision could be necessary as the current version is applied.

Conclusion

This study introduces the new nomenclature system (SOF system) of the CSD surgery to understand the surgical correction sequence, the grade of osteotomy, and the detail of the fixation techniques. The investigation of the inter- and intra-observer agreement among six independent observers revealed ‘excellent agreement’ for both anterior and posterior osteotomies.

Thus, this new classification system can provide a consistent description of the various osteotomies performed in cervical spine deformity surgery. Its use will provide a standard frame for cervical deformity correction surgery, communication between surgeons, and the evaluation of the CSD surgeries. However, further multicenter study is necessary to confirm whether the classification system is consistent and effective.

Acknowledgment We acknowledge that the material is not published previously.

Funding The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

Compliance with ethical standards

Conflict of interest The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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