



# A new method for calculating the desired laminoplasty opening size based on the target sagittal canal diameter before single-door cervical laminoplasty

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## Abstract

**Purpose** To build a mathematical model which could calculate the desired laminoplasty opening size (LOS) based on the target sagittal canal diameter (SCD) before single-door cervical laminoplasty (SDCL) when taking the effects of surgery drill into consideration.

**Methods** The model was based on geometric analysis on deformation of spinal canal; the formula was derived and characterized as:  $y$  (mm) =  $2 \overline{CD} \times \sin(\beta/2) = c - d$  ( $y$  is the size of LOS,  $\overline{CD}$  the size of transverse canal diameter,  $\beta$  the size of laminoplasty opening size,  $c$  the size of mini-plate and  $d$  the diameter of the drill bit used during the surgery operation). The parameters of pre- and postoperative computed tomography scans of 20 patients who had undergone SDCL were measured by the picture archiving and communication system (PACS) software and a new instrument named as Lei's ruler, respectively.

**Results** The effects of surgery SDCL were very significant; for each patient, the SCD was enlarged dramatically after the surgery ( $P < 0.01$ ). The differences between the data obtained by PACS and Lei's ruler were no statistically significant ( $P > 0.05$ ). According to the derived formula, the 95% confidence intervals of SCD after the surgery were within the range of 14 mm and 14.5 mm.

**Conclusion** Applying the mathematical model and derived formula, the desired LOS could be calculated according to the target SCD which could help the surgeon select an optimum mini-plate before SDCL. At the same time, a new measuring device named Lei's ruler is designed for the convenience of the derived formula.

## Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.

**Key points**

- Quite amount of clinic researches have been conducted on the investigation of relationship between LOS and SCD. However, the results of these research are not widely adopted on clinical operation due to the complex computation and the anatomical variations of patients. Meanwhile, they neglect the effects of the "worn-off" lamina tissue removed by the drill bit during the surgery operation.
- The aim of this study was to build a mathematical model which could calculate the desired LOS based on the target SCD before SDCL when taking the effects of surgery drill into consideration.
- Applying the mathematical model and derived formula, the desired LOS could be calculated according to the target SCD which could help the surgeon select an optimum mini-plate before SDCL. At the same time, a new measuring device named Lei's Ruler is designed for the convenience of the derived formula.

**The structure of the single door cervical laminoplasty:** DD: LOS; OA, preoperative SCD; OB, postoperative SCD;  $\alpha$ :  $\alpha$ :DCD; the laminoplasty opening angle.

**The details of Lei's Ruler:** Ruler  $b$  is connected to angle ruler  $a$  at P via a rotating bearing. Ruler  $c$  is connected to ruler  $b$  at Q. Ruler  $c$  can freely slide back and forth linearly within the straight slots in ruler  $b$ .

**Take Home Messages**

- Applying the mathematical model and derived formula, the desired LOS could be calculated according to the target SCD which could help the surgeon select an optimum mini-plate before SDCL.
- A new measuring device named Lei's Ruler is designed for the convenience of the derived formula which was proved to be valid.
- It can help a surgeon select an optimum mini-plate before SDCL with taking the effects of the "worn-off" lamina tissue removed by the drill bit into account.

Xiao-jiang Yang, Hong-xun Sang and Chen-xin Liu have contributed equally to this work.

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Extended author information available on the last page of the article

**Keywords** Cervical spine · Single-door cervical laminoplasty · Laminoplasty opening size · Sagittal canal diameter

## Introduction

Single-door cervical laminoplasty (SDCL) has been widely selected as the treatment for patients suffering from multi-level cervical spondylotic myelopathy (CSM), ossification of the posterior longitudinal ligament (OPLL) or multilevel cervical disk herniation associated with developmental spinal canal stenosis [1–3]. Generally, clinical follow-up studies have shown that SDCL yields more satisfying feedback from patients along with its long-term functionality [4–7], as well as lower complication rates than laminectomy [8–10].

The laminoplasty opening size (LOS) effectively determines the amount of sagittal canal expansion created during SDCL. Note that either inadequate or excessive LOS may lead to undesirable treatment results [11, 12]. Inadequate opening of canal is usually not enough to decompress the cord and, thus, does not relieve the symptoms. On the other hand, excessive opening of the lamina may cause extra problems, such as the occurrence of postoperative C5 nerve root palsy, or formation of more epidural scar tissues than expected, etc. [13–15].

Plenty of clinic researches have been performed on the investigation of relationship between LOS and sagittal canal diameter (SCD) [1, 16, 17]. However, the results of those researches are not widely adopted on clinical operation due to the complex computation and the anatomical variations of patients. Meanwhile, they neglected the effects of the “worn-off” lamina tissue removed by the drill bit during the surgery operation, which would result in undesired clinical operation errors [18].

The objective of the present research was to develop a simplified method for clinical operation of SDCL. The desired LOS could be conveniently calculated before the surgery based on the target SCD with the “worn-off” lamina tissue taken into consideration.

Furthermore, because of too many abbreviations in the text, we summarize those abbreviations in Table 1 for better reference.

## Materials and methods

### Patient data

This study included 20 sample patients (11 men, 9 women; CSM in 12 patients, OPLL in 8 patients) who have undergone C3–7 SDCL performed by the same surgeon at our institution from September 2016 to February 2018. All the target SCDs are 14 mm. The average age of sample subjects was 56.2 years (range 39–76 years). The median

duration history of symptoms before their surgery was 9.8 months (range 7–56 months). For each of them, conservative treatment, which was proved ineffective, has been attempted for 3 months before SDCL. Their magnetic resonance imaging confirmed spinal canal stenosis at C3–C7 levels with spinal cord compression because of cervical disk herniation or OPLL.

For the sake of simplicity, the left-hand side was set to be the lamina opening with the contralateral side acting as a hinge with a high-speed surgery hand drill. The center-piece mini-plates used in this study were from Medtronic (Medtronic Inc., Minneapolis, Minnesota, USA). The contract for these tests was officially approved and signed by each patient and the institutional ethics committee (no. 20160825).

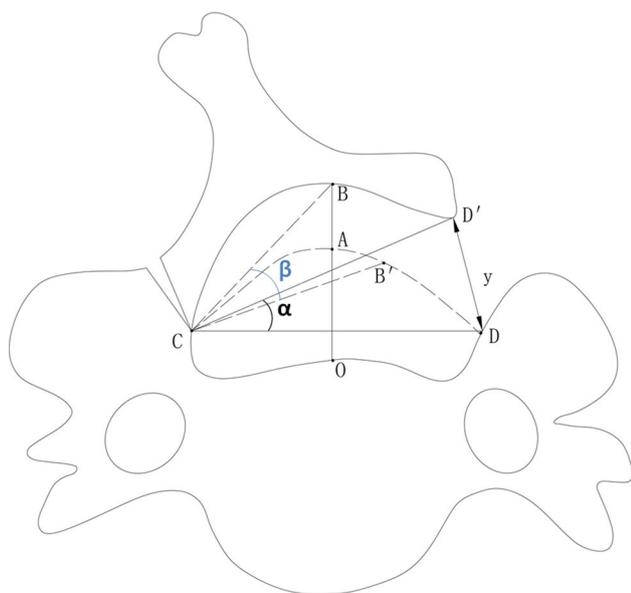
### Formula derivation

Preoperative and postoperative deformation in the cervical canal was measured and geometric characterization was derived to unveil the relationship between the LOS and the target SCD. The structure of SDCL is depicted in Fig. 1. The dashed curve C–A–D represents the shape of the inner edge of the lamina before surgery, while the solid curve C–B–D' is that after SDCL.

As shown in Fig. 1, C and D represent the most medial points of the bilateral laminar gutters; a straight line connecting C and D is defined as the transverse canal diameter (TCD). O is the midpoint on the central symmetry line of the vertebral body. Line O–A stands for a vertical line intersecting the inner lamina edge at A before surgery and at B after SDCL. Line O–A represents the preoperative SCD and line O–B stands for the postoperative SCD, which is also defined as the target SCD.

**Table 1** Abbreviations

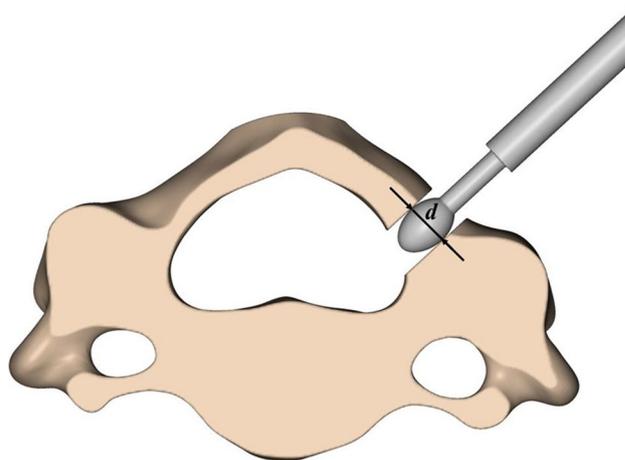
| English full name                                   | English abbreviations |
|---|-----------------------|
| Laminoplasty opening size                           | LOS                   |
| Sagittal canal diameter                             | SCD                   |
| Single-door cervical laminoplasty                   | SDCL                  |
| Picture archiving and communication system          | PACS                  |
| Cervical spondylotic myelopathy                     | CSM                   |
| Ossification of the posterior longitudinal ligament | OPLL                  |
| Transverse canal diameter                           | TCD                   |
| Laminoplasty opening angle                          | LOA                   |



**Fig. 1** The structure of the single-door cervical laminoplasty. The curves C–A–D and C–B–D' represent the shape of the inner edge of the lamina before and after SDCL, respectively. DD'(y) is laminoplasty opening size; OA the preoperative sagittal canal diameter; OB the postoperative sagittal canal diameter;  $\beta = \angle BCB'$ ;  $\alpha = \angle DCD'$ , the laminoplasty opening angle

D and D' represent the open sites of the lamina before and after surgery, respectively. Therefore, the distance between D and D', represented by y in Fig. 1, indicates the size of LOS. The angle  $\alpha$ ,  $\angle DCD'$ , is defined as the laminoplasty opening angle (LOA). A circle with radius of C–B centering at C intersects the curve C–A–D at B', forming an angle  $\beta$ ,  $\beta = \angle BCB'$ . Given the fact that the lamina was generally a rigid structure composed of bone and there was normally no significant flexible deformation during the procedure of operation, it was determined that  $\overline{CD} = \overline{CD'}$ . Coherently,  $\angle BCB' = \beta = \angle DCD' = \alpha$ . According to trigonometric functions in the triangle DCD',  $y = 2 \overline{CD} \times \sin(\alpha/2) = 2 \overline{CD} \times \sin(\beta/2)$ .

It is worth noting that some lamina tissue would be removed when preparing the lamina opening at the practical SDCL (see Fig. 2). The size of this “worn-off” lamina depends on the surgery drill bit diameter, which was represented as d in the equations. Meanwhile, the size of the mini-plate was represented as c. Therefore, the effective size of LOS would be the difference between the mini-plate size and the drill bit diameter, namely  $y \text{ (mm)} = 2 \overline{CD} \times \sin(\beta/2) = c - d$ . The formula is further modified as:  $c = 2 \overline{CD} \times \sin(\beta/2) + d$  (c is the size of mini-plate and d the diameter of the drill bit used during the surgery operation).



**Fig. 2** A high-speed hand drill used in single-door cervical laminoplasty. When preparing the lamina opening, some lamina tissue would be removed by the drill bit. The size of this “worn-off” lamina tissue depends on the drill bit diameter, represented as d in the modeling

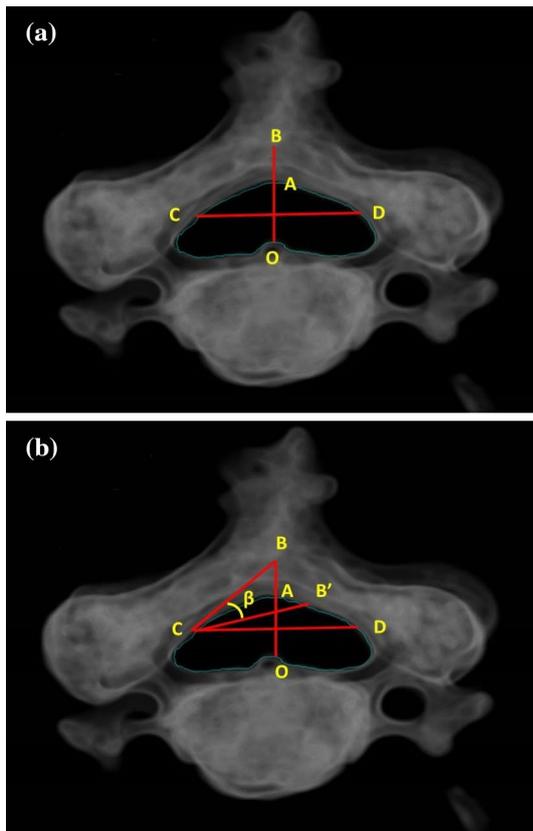
## Radiology

There are mainly two instruments for the parameter measurements. One of them is the software Picture Archiving and Communication System (PACS). The other is a new instrument designed and invented by Dr. Lei in our group which has obtained China National Invention Patent (CN201611209542.5). This new instrument was named Lei's ruler in this paper.

CT scans were obtained with the 64-slice computed tomography scanner (GE Light Speed 64-slice VCT, GE Healthcare, Milwaukee, WI, USA) for all the patients before and one week after their surgery. The scan started from C1 to C7. The scanning parameters include: tube voltage of 120 KVp, tube current–time product of 220 mAs, section thickness of 0.625 mm, reconstruction interval of 0.625 mm, gantry rotation time of 0.5 s, pitch of 0.925, matrix of  $512 \times 512$ , and a FOV of  $200 \times 200$  mm. After scanning, the raw data were transferred to GE post-processing workstation (ADW 4.4) and reconstructed into axial, coronal and sagittal images. Axial CT cuts made at each pedicle level from C3 to C7 were used for measurements.

## The method of PACS

The scanning image is shown in Fig. 3 (refer to Fig. 1 for physical meanings of relevant letters). The related measurements were taken on PACS (version 4.4, Huahai Healthcare, Xi'an, Shaanxi, China).



**Fig. 3** The instruction of measurements using PACS software. Measure the length of the line C–D and make O–B to be the target sagittal canal diameter (a). Draw a circle with its center at C and radius of C–B which intersect the curve C–A–D at B'. Measure the degree of the  $\angle BCB'$  ( $\beta$ ) (b)

*Step 1* (Fig. 3a) Connect C and D. B is determined by the target SCD, which is 14 mm in this study. In another words,  $OB = 14$  mm. Measure the length of the line C–D.

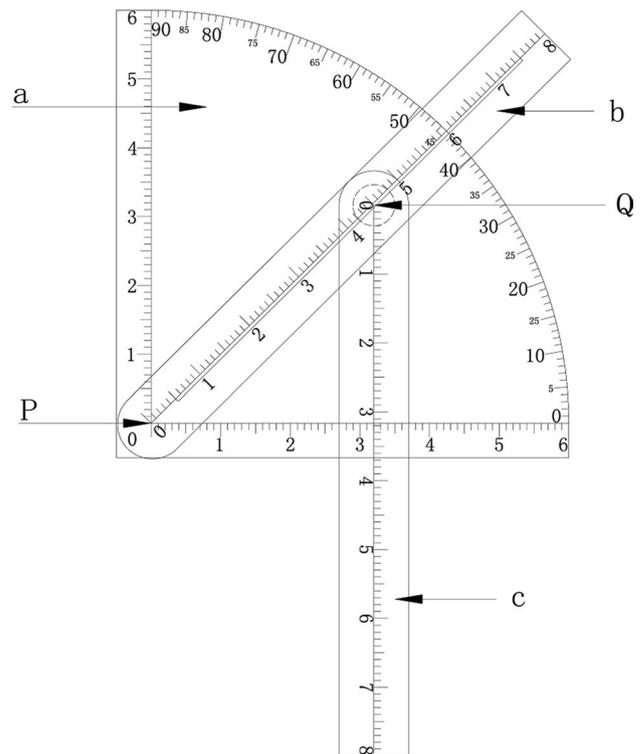
*Step 2* (Fig. 3b) A circle with its center at C and radius of C–B would intersect the curve C–A–D at B'. Measure the degree of the  $\angle BCB'$  ( $\beta$ ).

*Step 3* Plug in the measured dimensions,  $c = 2 CD \times \sin(\beta/2)$  ( $c$  is the size of mini-plate and  $d$  the diameter of the drill bit used during the surgery operation which is 2 mm in this study).

**Lei’s ruler**

Lei’s ruler was designed and invented for convenient measurements of related footprints during the surgery operation of SDCL. This ruler is capable to measure the length C–D and angle  $\beta$  simultaneously on the CT photograph before surgery.

As sketched in Fig. 4, Lei’s ruler is comprised of three main components, including angular ruler  $a$ , straight ruler



**Fig. 4** The details of Lei’s ruler. Ruler  $b$  is connected to angle ruler  $a$  at P via a rotating bearing. Ruler  $c$  is connected to ruler  $b$  at Q. Ruler  $c$  can freely slide back and forth linearly within the straight slots in ruler  $b$

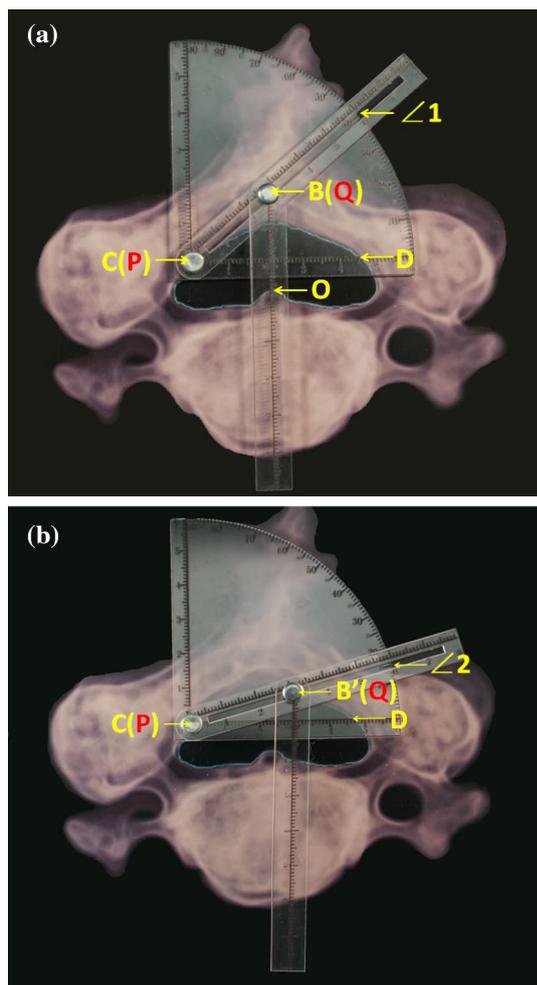
$b$  and straight ruler  $c$ , respectively. Ruler  $b$  is connected to ruler  $a$  at P via a rotating bearing. On the other hand, ruler  $c$  is connected to ruler  $b$  at Q. Ruler  $c$  can freely slide back and forth linearly within the straight slots in ruler  $b$ .

The manual of Lei’s ruler is detailed in the following steps (refer to Fig. 1 for physical meanings of relevant letters).

*Step 1* (Fig. 5a) Measure the length of line C–D by the bottom marks of ruler  $a$ . Rearrange Rulers  $b$  and  $c$  to ensure that the mark line of ruler  $c$  is colinear with the center symmetric line of C–D, and ruler  $c$ ’s reading (i.e., O–B) is the target SCD, i.e.,  $OQ = 14$  mm in this case. Take a record of the angular reading of ruler  $b$  on ruler  $a$ , marked as  $\angle 1$ .

*Step 2* (Fig. 5b) Maintain the relative position of ruler  $c$ ’s origin unchanged with respect to ruler  $b$ ; PQ is kept constant. On the other hand, slowly rotate ruler  $b$  clockwise with respect to P until the mark line of ruler  $b$  intersects with arc C–A–D. The intersection point is marked as B'. Take a second record of ruler  $b$ ’s angular measurements on ruler  $a$ , marked as  $\angle 2$ . Herein,  $\angle \beta = \angle BCB' = \angle 1 - \angle 2$ .

*Step 3* Plug in the measured value,  $c = 2$  Plug in the measured dimensions  $\times \sin(\beta/2)$  ( $c$  is the size of mini-plate and



**Fig. 5** The instruction of measurements using Lei's ruler. Measure the length of the line C–D by the bottom of angle ruler *a*; make ruler *c*'s reading (i.e., O–B) reach the target sagittal canal diameter; and then take a record of the angular reading of ruler *b* on ruler *a*, marked as  $\angle 1$  (a). Keep P–Q constant, rotate ruler *b* until intersects arc C–A–D at B', and then take a record of ruler *b*'s angle measurements on ruler *a*, marked as  $\angle 2$  (b)

**Table 2** Intraobserver and interobserver reliability with Cronbach's alpha values for two independent team members, A and B

| Parameters        | PACS                      |       | Interobserver reliability | Lei's ruler               |       | Interobserver reliability |
|-------------------|---------------------------|-------|---------------------------|---------------------------|-------|---------------------------|
|                   | Intraobserver reliability |       |                           | Intraobserver reliability |       |                           |
|                   | A                         | B     |                           | A                         | B     |                           |
| Preoperative SCD  | 0.924                     | 0.931 | 0.902                     | 0.913                     | 0.908 | 0.883                     |
| Postoperative SCD | 0.912                     | 0.917 | 0.892                     | 0.916                     | 0.901 | 0.895                     |
| Length of C–D     | 0.918                     | 0.921 | 0.910                     | 0.921                     | 0.907 | 0.901                     |
| $\beta$ (LOA)     | 0.904                     | 0.893 | 0.885                     | 0.896                     | 0.887 | 0.863                     |

The measurements were taken by PACS and Lei's ruler

SCD sagittal canal diameter; length of C–D indicates the transverse canal diameter; LOA indicates the laminoplasty opening angle

*d* the diameter of the drill bit used during the surgery operation which is 2 mm in this study).

In order to improve the measurement accuracy, the CT photographs were magnified to twice their ordinary size. The target SCD should thus be 28 mm ( $14 \text{ mm} \times 2$ ). Accordingly, the formula was further modified as:  $c = 2 \overline{CD} \times \sin(\beta/2)/2$ .

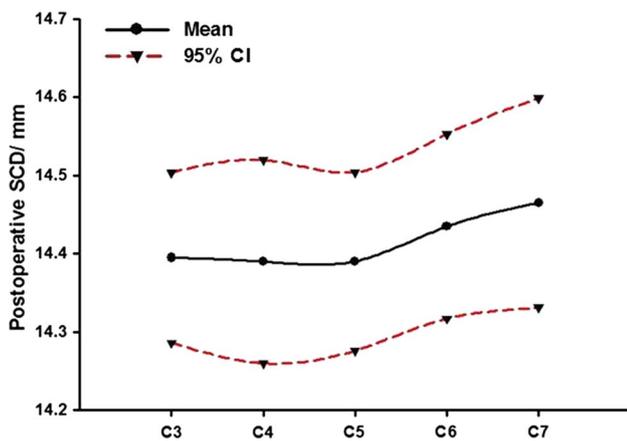
### Statistical analysis

The related values were measured by two methods (PACS and Lei's ruler) at the same time with accuracy within 0.1 mm, or 0.1°. Two of the authors conducted data measurements independently three times to ensure accuracy. The intraobserver and interobserver reliability with Cronbach's alpha values is all higher than 0.85 in this project, which confirmed satisfactory consistence of all the manual measurement (Table 2). The average values of their measurements were used for analysis variables in this study, in order to achieve a high standard of reliability.

Statistical analysis was performed on software SPSS version 24.0 (SPSS, Inc., Chicago, IL). Data were displayed as the mean ( $\pm$  standard deviation [SD]) at a significance level of  $P < 0.05$ . The differences between the data obtained by PACS and measurements were evaluated with the paired *t* test.

### Results

In the present research, all the surgery operations were fully prepared and successfully conducted. For each patient, the SCD was enlarged dramatically after the surgery ( $P < 0.01$ ). The 95% confidence intervals of the postoperative SCD were within the range of 14 mm and 14.5 mm when the target SCD was 14 mm, which in turn



**Fig. 6** The 95% confidence intervals of the postoperative sagittal canal diameter were within the range of 14 mm and 14.5 mm when the target sagittal canal diameter was 14 mm

**Table 3** Comparison of pre- and postoperative sagittal canal diameter (SCD)

|    | Preoperative SCD | Postoperative SCD | <i>P</i> | <i>n</i> | Increase in SCD |
|----|------------------|-------------------|----------|----------|-----------------|
| C3 | 8.4 mm (±0.9)    | 14.4 mm (±0.2)    | <0.01    | 20       | 5.8 mm (±0.6)   |
| C4 | 8.8 mm (±0.6)    | 14.3 mm (±0.3)    | <0.01    | 20       | 5.4 mm (±0.8)   |
| C5 | 8.6 mm (±0.5)    | 14.4 mm (±0.2)    | <0.01    | 20       | 5.7 mm (±0.7)   |
| C6 | 8.6 mm (±0.7)    | 14.3 mm (±0.4)    | <0.01    | 20       | 5.7 mm (±0.4)   |
| C7 | 8.7 mm (±0.6)    | 14.2 mm (±0.3)    | <0.01    | 20       | 5.6 mm (±0.6)   |

proved the accuracy and reliability of the derived formula (Fig. 6).

According to the measurements of both PACS and Lei’s ruler, the length of C–D for C3–C7 is discovered to be C6 > C5 > C7 > C4 > C3. C6 has the maximum length of C–D with 19.6 ± 0.5 mm/19.8 ± 0.6 mm from PACS/Lei’s ruler, respectively, while C3 has the minimum C–D length of 17.3 ± 0.6 mm and 17.2 ± 0.6 mm, respectively (Table 1). In

the measurements of both PACS and Lei’s ruler, C3 has the maximum β (LOA) of 35.9 ± 6.5° and 36.1 ± 6.6°, respectively, whereas the minimum β (LOA) was at C6 (31.2 ± 4.8° and 31.4 ± 4.7° correspondingly) when the target SCD is 14 mm (Table 3). The comparison of β (LOA) and C–D length obtained by PACS and Lei’s ruler indicated no significant difference (*P* > 0.05), respectively, which verified the high consistence of these two systems (Table 4). It confirmed the precise functionality and effectiveness of Lei’s ruler designed and presented in this paper.

### Discussion

For past decades, the SDCL has proved its excellent practical success, as well as its satisfying long-term reliability in clinical treatment of cervical spinal stenosis [19, 20]. In addition, it is acknowledged that the centerpiece mini-plate plays a key role in the surgery operation. According to the reports, the mini-plates are proved to be the primary selection for SDCL because of their safe quality and operational convenience [21–23].

In clinical practices, the research group noticed that previous SDCL-related clinic researches neglected the effects of the “worn-off” lamina tissue removed by the drill bit during the surgery operation. It would result in undesired clinical operation errors even though these errors are very small. Therefore, our group have conducted an investigation on the relationship of LOS and the spinal canal cross-sectional area with the “worn-off” lamina tissue taken into consideration [18]. A mathematical model was thus constructed that the increment of the cross-sectional area can be estimated before the SDCL [18]. Nonetheless, the LOS is also critical in the SDCL for its influence on the increment of SCD. The “worn-off” lamina tissue removed by the drill bit would affect on the SCD as well. Therefore, plenty of clinic research have been performed on investigation of relationship between LOS and SCD [1, 4–7, 16, 17]. Itoh and Tsuji [16] noted that a 4.1-mm enlargement of the SCD was ideal and it could be achieved by extending the LOS to 8 mm. Other physicians suggested that the optimum enlargement of the SCD by laminoplasty is within 4–5 mm [1, 17]. In

**Table 4** Comparison of the data obtained by picture archiving and communication system (PACS) and Lei’s ruler using the paired *t* test (*n* = 20)

|    | β (LOA)      |              | <i>P</i> | Length of C–D  |                | <i>P</i> |
|----|--------------|--------------|----------|----------------|----------------|----------|
|    | PACS         | Lei’s ruler  |          | PACS           | Lei’s ruler    |          |
| C3 | 35.9° (±6.5) | 36.1° (±6.6) | 0.775    | 17.3 mm (±0.6) | 17.2 mm (±0.6) | 0.824    |
| C4 | 32.4° (±5.4) | 32.6° (±5.2) | 0.564    | 17.8 mm (±0.6) | 17.5 mm (±0.5) | 0.787    |
| C5 | 32.7° (±4.3) | 32.4° (±4.1) | 0.449    | 19.0 mm (±0.4) | 18.9 mm (±0.3) | 0.436    |
| C6 | 31.2° (±4.8) | 31.4° (±4.7) | 0.843    | 19.6 mm (±0.5) | 19.8 mm (±0.6) | 0.684    |
| C7 | 32.5° (±4.1) | 32.7° (±3.9) | 0.532    | 18.5 mm (±0.3) | 18.4 mm (±0.4) | 0.571    |

LOA laminoplasty opening angle

practice, the theoretical research results cannot be widely utilized on clinical operation for individual anatomical variations of the patients.

In the practical SDCL surgery, the LOS is closely related to the size of selected mini-plate. Therefore, it is critical to ensure an optimum selection of the mini-plate for each individual surgery, whereas so far there has not yet been a widely accepted standard for selection of mini-plate, which is instead essentially based on the experience of the surgery operator. It would potentially lead to undesired surgery results.

It is also worth noting that some tissue segment of lamina would be removed when preparing the lamina opening using a high-speed hand drill at the clinic operation. The size of this “worn-off” lamina depends on not only the surgery drill bit diameter but also how the drill is operated. To avoid the lateral mass, the high-speed drill should be perpendicular to the lamina when preparing the lamina opening. In this case, the size of this “worn-off” lamina is equal to the drill bit diameter. For instance, the loss of lamina varies from 1.5 mm to 4 mm depending on the drill bit diameter [24]. This removal of lamina tissue was normally neglected in the calculation in previous researches. However, taking this “tissue loss” into consideration is proved to be more precise. Thus, a new variable was proposed in the present modeling; it was defined as the actual LOS, namely the difference between the mini-plate size and the drill bit diameter. For instance, if a mini-plate of 12 mm has been selected for SDCL and the drill bit diameter is 2 mm, the actual LOS is not 12 mm because some lamina has been removed when preparing the lamina opening by the drill. Hence, the actual LOS would be the difference between the mini-plate size and the drill bit diameter, namely 10 mm.

The main object of this research is seeking a standard that makes it more convenient and precise for a surgeon or operator to select a mini-plate and drill bit for each specific surgery. The present research is mainly focused on the target SCD, rather than only on the increase in SCD. Namely, the target SCD is presumed for calculation of the necessary LOS. Each cervical vertebra will be measured accordingly and plugged in the derived equations to determine the LOS value before surgery; the results are referred to for the surgeon to achieve more precise and satisfactory operation conveniently.

Aiming at maintaining a sufficient SCD, the target SCD is assumed 14 mm in the present research [25]. Note that the target SCD would be other values for a different physician depending on his/her knowledge background and patients. Besides, the available size of mini-plates in the market varies in 8 mm, 10 mm, 12 mm, 14 mm and 16 mm. Considering the inevitable inconsistency between the available mini-plate dimension and calculated LOS, the mini-plate of closest and larger size will be selected for the surgery. For instance, a

mini-plate of 12 mm would be selected when the calculated LOS is 11.2 mm. Therefore, the realistic SCD after the surgery would be slightly bigger than the target SCD (14 mm), which was proved to be practically acceptable. Hence, the SCD after surgery turned out to be between 14 and 14.5 mm in this study.

Note that the debate about the ideal size for SCD is not yet finalized in the academic research. The main objective of the present work is to calculate LOS based on a target SCD. The results could be applied for different patients/physicians. During the operation, the LOS for different target SCDs could be determined by simply varying the value of O–B (Figs. 3a, 5a). Hirabayashi et al. [1] reported that optimal widening of the SCD was > 4 mm. In such a case, if a surgeon was more interested in the enlargement of SCD, the formula can be modified by just assuming the length of O–B to be the summation of preoperative SCD and its increment.

For the sake of convenience, the PACS is the best choice for the measurements according to the derived formula. The raw data are essential for PACS which should be transferred to GE post-processing workstation and reconstructed into images. In the actual work, there are some problems: (1) Not all hospitals have the PACS; (2) most surgeons are not familiar with the PACS; (3) some patients from other hospitals have only relevant CT photograph, but no raw data. For these problems, we designed the new measuring device named Lei’s ruler, functioning well with the preoperative CT photograph. Our results also confirmed the reliability and effectiveness of Lei’s ruler.

It is also worth mentioning that, in the realistic world, the scale of printed CT graph is different from case to case. This scale difference results in variation of  $\overline{CD}$  and the target SCD (value of O–B in Fig. 5a). Thereafter, the modified formula when using Lei’s ruler would be  $c = 2 \overline{CD} \times \sin(\beta/2)/m + d$  ( $c$  is the size of mini-plate,  $d$  the diameter of the drill bit and  $m$  the scale value of the printed CT graph).

## Study limitations

In application of Lei’s ruler, the CT graph is scaled up 2× to enhance the measurement accuracy. Note that normally the CT graph has a smaller size, which would increase the measurement errors. Besides, it is usually suggested that lateral hinges should be located at the medial border of the facet joints [11, 12]. However, it is difficult to find the exact same position for all surgeries, even though the procedures were conducted by the same surgeon to reduce the variance as much as possible in this study. Also, the measurement accuracy would be affected by other factors, one of which could be the deflection from the exact location of CT scan.

It is worth noting that the amount of bone loss is dependent on the way a drill is used. To avoid the lateral

mass, the high-speed drill should be perpendicular to the lamina when preparing the lamina opening. In this case, the size of this “worn-off” lamina is equal to the drill bit diameter. However, the high-speed drill was more than often used in an angled position in clinical practice. If so, the “worn-off” lamina would be bigger than the drill bit diameter. In order to minimize such an error, the surgeon should try to keep the high-speed drill perpendicular to the lamina based on the imaging data of the patients and sufficient intraoperative exposure.

Although the desired LOS could be calculated according to the target SCD which would enable the surgeon to select an optimum mini-plate before SDCL, the precise implantation of mini-plate is also the key to success. The LOS will be larger than calculated if the mini-plate is not precisely implanted. Only through skillful technique and careful operation will the accurate position of the mini-plate be guaranteed.

## Conclusion

This study built a mathematical model based on geometric analysis on deformation of spinal canal. Applying the mathematical model and derived formula, the desired LOS could be calculated according to the target SCD which could help a surgeon select an optimum mini-plate before SDCL with taking the effects of the “worn-off” lamina tissue removed by the drill bit into account. At the same time, a new measuring device named Lei’s ruler is designed for the convenience of the derived formula which was proved to be valid.

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## Compliance with ethical standards

**Conflict of interest** There are no ethical/commercial or any other relationships that might lead to conflict of interest in the article.

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