의학석사 학위논문

개방문 추궁성형술과 양문 추궁성형술에서 추궁각과 척추관 넓이 확장

Lamina angle and spinal canal expansion in open-door and double-door laminoplasty

2017년 8월

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정 종 명

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이 논문을 의학석사 학위논문으로 제출함

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정 종 명

정 종 명의 석사학위논문을 인준함

2017년 7월

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Abstract

Lamina angle and spinal canal expansion in open-door and double-door laminoplasty

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Background

Open-door and double-door laminoplasty (ODL and DDL, respectively) have been widely used for the treatment of multilevel cervical stenotic conditions. However, the comparison of post-operative spinal canal expansion between the two techniques relative to the pre-operative lamina angle has not been investigated.

Objective

To verify the accuracy of the simulation model and to predict the spinal canal expansion after laminoplasty (ODL and DDL) relative to the pre-operative lamina angle.

Methods

The parameters including length, angle and area of 64 patients who had undergone C3-C6 laminoplasty (43 patients with ODL and 21 patients with DDL) were m

easured on computed tomography scans by picture archiving and communication system software. The GeoGebra software was used to simulate laminoplasty. The accuracy of the simulation was evaluated by comparing the clinical data with the simulation data. ODL and DDL were simulated to determine the amount of canal enlargement at various pre-operative lamina angles.

Results

A comparison of the data obtained by clinical investigation and simulation showed no significant difference ($p > 0.05$)andaveryhighdegreeofcorrelation($p < 0.001$). The increase in the spinal canal area (SCA) of ODL cases was significantly greater than that of DDL cases when the pre-operative lamina angle was 32° and less; however, the increase in the SCA of DDL cases was significantly greater than that of ODL cases when the pre-operative lamina angle was 33° and more.

Conclusion

When the pre-operative lamina angle was 32° and less, ODL is advantageous in terms of an increase in SCA.

Key words: open-door laminoplasty, double-door laminoplasty, lamina angle, spinal canal expansion

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Introduction

Cervical laminoplasty is considered an effective and safe method for decompressing cervical lesions caused by cervical spondylotic myelopathy (CSM) or ossification of the posterior longitudinal ligament (OPLL).[1-6] Several types of laminoplasty have been described in recent decades. Current laminoplasty techniques tend to fall into one of two categories, open-door or double-door laminoplasty (ODL and DDL, respectively). Each procedure preserves the lamina but expands the size of the spinal canal by placing the partially freed lamina in a more posterior position to produce a wider spinal canal. Some investigators have studied the expanded areas of the two different techniques. However, the comparison of post-operative spinal canal expansion between ODL and DDL relative to the pre-operative lamina angle has not been investigated.

We designed a simulation of the expanded area of a hypothetical spinal canal. Furthermore, we compared the expansion areas for different laminoplasty techniques according to the pre-operative lamina angle to determine their appropriate surgical indications.

Methods

Patient Population

Between January 2012 and December 2016, we treated 157 patients with CSM or OPLL through cervical laminoplasty. Patients with cervical deformities, trauma, infection, and previous cervical spine surgery were excluded in this study. We retrospectively analyzed the outcomes of 64 consecutive patients (51 men, 13 women) who

underwent cervical laminoplasty of C3-C6. Of the 64 patients, 16 were diagnosed with CSM, and 48 were diagnosed with OPLL. The study included 43 ODL patients and 21 DDL patients. The two groups did not differ significantly in baseline clinical characteristics (Table 1). The present study was approved by the Institutional Review Board of the hospital (B-1705/395-107).

Table 1. Baseline clinical characteristics of the two groups,

	Open-door laminoplasty (n=43)	Double-door laminoplasty (n=21)	*p*-value
Mean age (y)	63.3 ± 12.0	59.9 ± 7.5	0.170
Sex (Male:Female)	35 : 8	16 : 5	0.627
Diagnosis (CSM:OPLL)	10 : 33	6 : 15	0.645

The values represent the means ± the standard deviations.

CSM, cervical spondylotic myelopathy; OPLL, ossification of posterior longitudinal ligament

Surgical Technique

For ODL, a longitudinal trough of 3 mm in width was made using a diamond burr along the lamina-facet junction line at the hinge side of the lamina, leaving the inner cortex undisturbed. Then, a similar trough was made on the open side, and finally, the inner cortex was severed longitudinally. Next, the spinous process was pushed to hinge side with a finger. The lamina was kept elevated using miniplate or

centerpiece plate (Medtronic, Memphis, United States) bridging the lamina and facet joint on the open side.

For DDL, troughs were created at the bilateral lamina-facet junctions using a 3 mm diameter diamond burr, and the midline spinous process was split with a 2 mm diameter diamond burr. A hydroxyapatite block (APACERAM, PENTAX, Tokyo, Japan) was inserted between the split spinous processes and fixed with 1.0 black silk sutures.

Model Construction and Validation

Computed tomography (CT) scanning of all patients was performed with a slice thickness of 3 mm. Axial CT cuts at each of the respective pedicle levels from C4 and C5 were used for measurement because the canal at the C3 and C6 levels could not be fully opened due to the tension of the nuchal ligament or the adjacent interspinous ligament. The distances from points A to B and from points A to C´, the pre-operative lamina angle (α) and the lamina opening angle (LOA)(β) were measured with an accuracy within 0.01 mm, or 0.01° in ODL (Figure 1A). The distances from points E to F, from points G´ to G´´, the pre-operative lamina angle (α) and the LOA (β) were also measured for DDL images (Figure 1B). The pre-and post-operative spinal canal diameter (SCD) and spinal canal area(SCA) were measured directly on the CT image. SCD was the length from the lamina roof pitch to posterior side of vertebral body and SCA was defined as the area enclosed by lamina, pedicle and posterior side of vertebral body (Figure 2). All parameters including length, angle and area were measured using INFINITT picture archiving and communication system (PACS) software. Two clinicians independently evaluated allimages two times, and the mean value was

used for analysis.The intra-observer errors were less than 5%.

The GeoGebra software was used to simulate ODL and DDL (Figure 3). GeoGebra is a mathematics software program for all levels of education that brings together geometry, algebra, spreadsheets, graphing, statistics and calculus. A validation study was performed to assess the accuracy of the simulation model in reproducing the cervical laminoplasty. Pre- and post-operative CT scans of 64 patients who had previously undergone either ODL or DDL were analyzed to determine the increase in SCD and SCA using our PACS software.Then,the same length and angle as those of the patients who actually underwent surgery were used in the simulation, and the increases in SCD and SCA were assessed.

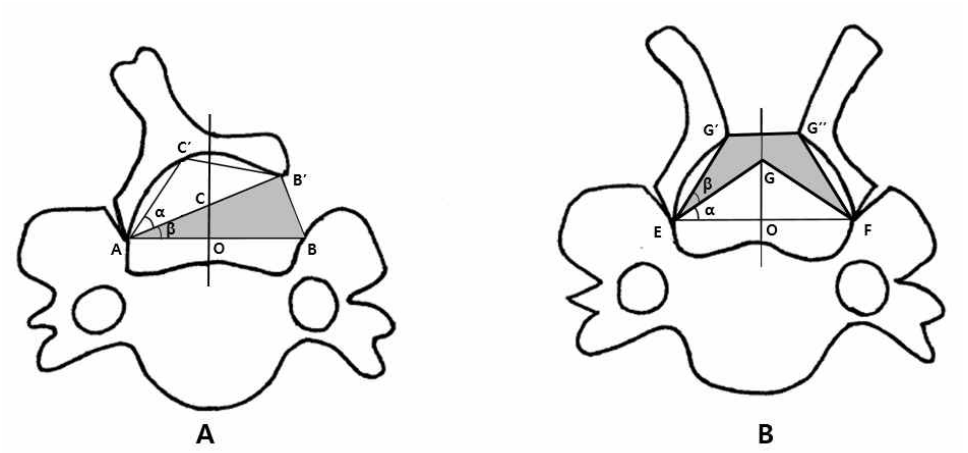

Figure 1. Radiologic parameters used in the study. Open-door laminoplasty (A) and double-door laminoplasty (B). The shaded area shows the increase in the spinal canal area. α indicates the pre-operative lamina angle, and β indicates the laminoplasty opening angle.

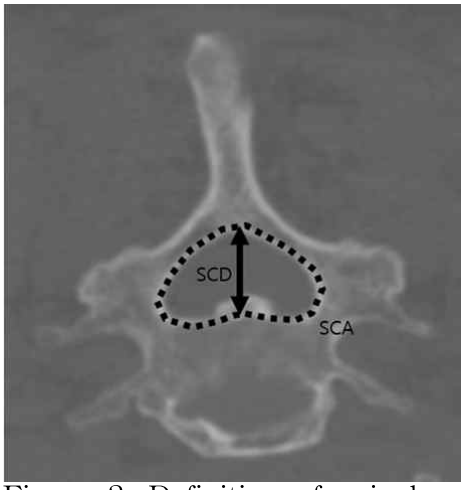

Figure 2. Definition of spinal canal diameter (SCD) and spinal canal area (SCA). SCD was the length from the lamina roof pitch to posterior side of vertebral body and SCA was defined as the area enclosed by lamina, pedicle and posterior side of vertebral body

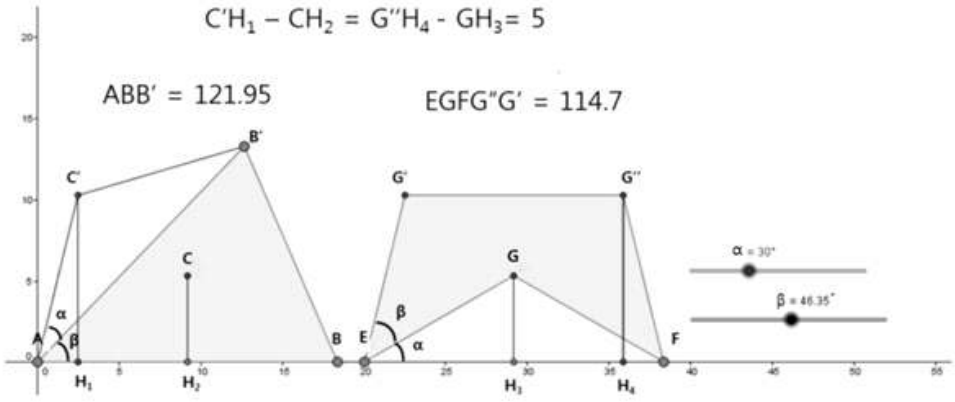

Figure 3. Images after surgical simulation using the GeoGebra program. Open-door laminoplasty and double-door laminoplasty. The increase in spinal canal area (shaded area) is shown. By setting pre-operative lamina angle (α) and lamina opening angle (β), changes in spinal canal diameter and spinal canal area after laminoplasty (open-door or double-door) can be predicted.

Statistical Analysis

The statistical analysis was performed using SPSS version 21.0 software (SPSS, Inc., Chicago, IL). Data are expressed as the mean ± standard deviation at a significance level of $p < 0.05$. The differences in SCD and SCA change between CT measures and simulation were evaluated with a paired t test. The correlation in SCD and SCA change between CT measures and simulation were assessed by calculating Pearson's correlation coefficient.

Results

A comparison of clinical data and the simulation study showed no significant difference ($p > 0.05$) and a high degree of correlation ($p < 0.001$) (Table 2). Therefore, the validity of the simulation model is supported.

Simulations were performed using the actual measured values of the patients participating in the study, except for the pre-operative lamina angle. Laminoplasty with pre-operative lamina angles of 30°, 45° and 60° was simulated to determine the increase in the SCA (Figure 4). The SCA gradually increased following either ODL or DDL. The increase in the SCA of ODL cases was constant regardless of the pre-operative lamina angle. When the pre-operative lamina angle was 30°, the increase in the SCA of ODL cases was larger than that of DDL cases until the LOA reached 60°. When the pre-operative lamina angle was 45 or 60°, the increase in the SCA of DDL cases was always larger than that of ODL cases, regardless of the LOA. The pre-operative lamina angle was simulated from 30° to 45°, and the increase in the SCA of laminoplasty (ODL and DDL) was examined.

The target LOA was determined when the change in the SCD was 5 mm. If the change in SCD could not be 5 mm, the target LOA was set when the change in SCD was at its maximum. The increase in the SCA of ODL cases was significantly greater than that of DDL cases when the pre-operative lamina angle was 32° and less (Table 3); however, the increase in the SCA of DDL cases was significantly greater than that of ODL cases when the pre-operative lamina angle was 33° and more.

Table 2. Comparison of the data obtained by CT scans and the data obtained by the simulation (the GeoGebra program) using a paired t-test and Pearson correlation analysis.

	CT measures	Simulation	t-value (*p*-value)	r-value (*p*-value)
ODL, C4				
Increase in SCD (mm)	5.32 ± 0.59	5.29 ± 0.65	1.383 (0.177)	0.993 **(< 0.001)**
Increase in SCA (mm^2)	120.85 ± 11.62	119.17 ± 9.82	1.264 (0.214)	0.994 **(< 0.001)**
ODL, C5				
Increase in SCD (mm)	5.01 ± 1.90	5.05 ± 1.89	1.431 (0.162)	0.995 **(< 0.001)**
Increase in SCA (mm^2)	117.61 ± 11.32	115.90 ± 8.81	1.11 (0.278)	0.999 **(< 0.001)**
DDL, C4				
Increase in SCD (mm)	5.12 ± 0.40	5.18 ± 0.42	1.470 (0.157)	0.901 **(< 0.001)**
Increase in SCA (mm^2)	119.87 ± 12.21	118.74 ± 10.82	1.037 (0.310)	0.945 **(< 0.001)**
DDL, C5				
Increase in SCD (mm)	4.81 ± 1.85	4.76 ± 1.82	1.393 (0.181)	0.904 **(< 0.001)**
Increase in SCA (mm^2)	113.99 ± 10.58	111.15 ± 7.23	1.314 (0.204)	0.910 **(< 0.001)**

The values represent the means ± the standard deviations.

Boldface type indicates statistical significance.

CT, computer tomography; ODL, open-door laminoplasty; DDL, double-door laminoplasty; SCD, spinal canal diameter; SCA, spinal canal area

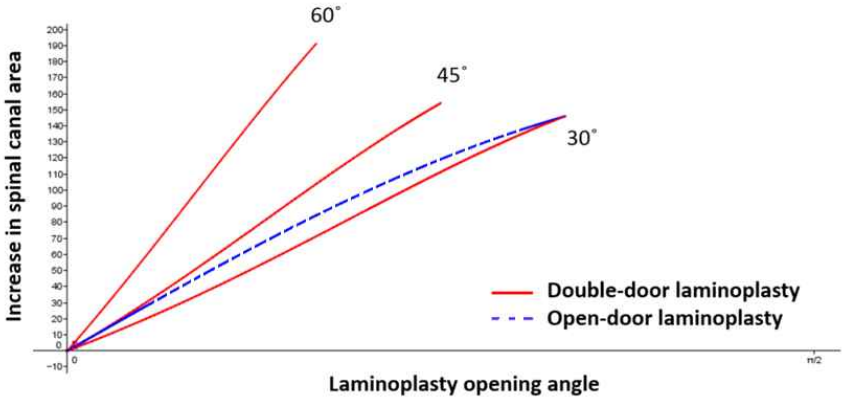

Figure 4. Increases in the spinal canal area after open-door laminoplasty and double-door laminoplasty according to pre-operative lamina angle. The increase in the spinal canal area after open-door laminoplasty was constant regardless of the pre-operative lamina angle. However, the increase in the spinal canal area after double-door laminoplasty was changed according to the pre-operative lamina angle.

Table 3. Comparison of the increase in the SCA between ODL and DDL.

Pre-operative lamina angle (°)	Increase in SCA (mm^2)		*p*-value
	ODL	DDL	
30	121.91 ± 0.89	114.26 ± 0.88	**< 0.001**
31	125.05 ± 0.86	121.24 ± 0.77	**< 0.001**
32	130.04 ± 0.84	129.29 ± 0.79	**0.001**
33	141.13 ± 0.82	146.16 ± 0.86	**< 0.001**
34	139.04 ± 0.84	146.31 ± 0.82	**< 0.001**
35	138.17 ± 1.33	146.38 ± 0.75	**< 0.001**

The values represent the means ± the standard deviations.

Boldface type indicates statistical significance.

SCA, spinal canal area; ODL, open-door laminoplasty; DDL, double-door laminoplasty

Discussion

No significant difference was observed in the clinical results of ODL and DDL.[7, 8] Both methods provide sufficient canal expansion to produce a dorsal spinal cord shift of more than 3 mm, which is associated with good surgical outcomes.[9]

For surgery, the factor that should be considered is the degree to which the lamina should be opened. Either insufficient or excessive opening may lead to undesirable results after laminoplasty. Insufficient opening of the canal is not sufficient to decompress the cord and thus may not improve the clinical outcome. Excessive opening of the lamina may cause the cord to migrate and extend posteriorly to an excessive degree, which can lead to the occurrence of post-operative C5 nerve root palsy.[10] Furthermore, the incidence of radiculopathy was significantly increased among patients with a large angle (≥ 60°) of the lamina after expansion.[11] Excessive opening also creates a wider epidural space and induces the formation of more epidural scar tissues than would normally be expected.[12]

A positive correlation exists between the likelihood of functional spinal cord recovery and the degree of spinal cord decompression. The optimal increase in the sagittal diameter of the stenotic canal by laminoplasty is > 4 - 5 mm.[13-15] The good recovery group showed optimal widening by 5 mm in diameter and an increase of 95 mm^2inthecanalarea.[13] Based on these results, we simulated the optimal LOA when the increase in SCD was 5 mm.

Some investigators have studied the expanded areas obtained using the two different techniques. A common method of these reports was the use of an image analysis program to determine the expanded

area. However, this process is subject to several types of errors. First, the image analysis method is not completely accurate, even if the image is magnified. Second, the measured area can differ across persons or repeated measurements. Third, the post-operative images may not show the same section as the pre-operative images. Therefore, we devised a new method to precisely define the increase in SCD and SCA with various LOAs. This method could be used in future spinal research.

In the current study, the expanded area produced using ODL was significantly larger than that produced using DDL until the pre-operative lamina angle reached approximately 32°. Since most people have a cervical lamina angle less than 32°, ODL may be a better technique in terms of increasing the SCA. The results of the current study were similar to those of previous reports.[12, 16, 17]

Limitations

Clinically, the bone is removed when preparing the lateral gutter or when splitting the lamina, and the surgeon, the technique and instruments used influence the quantity of bone removed. For example, when splitting the lamina in double-door laminoplasty, almost no bone is removed when the T-saw procedure is used, but when using a burr, the loss of bone is substantial. Additionally, use of a small diamond burr (1.5 mm) will remove less bone than large burr (4 mm). However, the present simulation model did not consider the amount of bone removed. In reality, the increase in SCA will be equal to the value calculated by the simulation plus the amount of the removed bone.

If the planned position of the lateral hinges did not agree with the

actual surgical positioning of the lateral hinges or the lateral gutter positioning was asymmetrical, a small difference from the calculated result was observed.

In double-door laminoplasty, the position of the spacer is not always located in the lamina roof pitch. Depending on the position of the spacer, the increase in SCA is variable and may differ from the simulation result.

Although this simulation accurately described the relationship between the increase in canal expansion after laminoplasty according to the pre-operative lamina angle, further studies are required to obtain the clinical information.

Conclusion

We designed a simulation model for the expanded area of the spinal canal after cervical laminoplasty. The canal enlargement following ODL or DDL could be predicted by the simulation. Considering the average lamina angle, the expansion area after ODL will be greater than that after DDL. However, it is necessary to consider clinical outcomes and understand the advantages and disadvantages of each surgical method.

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국문초록

개방문 추궁성형술과 양문 추궁성형술에서 추궁각과 척추관 넓이 확장

배경

여러층(multilevel)의 경추 협착 증상의 치료에는 개방문 추궁성형술 및 양문 추궁성형술이 널리 사용되어왔다. 그러나, 수술 전 추궁각에 따른 두 기법 간의 수술 후 척추관 확장의 비교에 대한 연구는 아직 없었다.

목적

모의실험 모델 (simulation model)의 정확성을 확인하고, 수술전 추궁각에 따른 추궁성형술 (개방문 추궁성형술 및 양문 추궁성형술) 이후 척추관 넓이의 확장을 예측해 본다.

방법

경추 3번-6번 추궁성형술을 시행한 64명 환자들 (개방문 추궁성형술 43명, 양문 추궁성형술 21명)의 CT에서 길이, 각도 및 면적을 포함한 측정값들을 PACS 소프트웨어를 이용하여 측정하였다. GeoGebra 소프트웨어는 추궁성형술을 모의실험하는 데 사용되었다. 시뮬레이션의 정확성은 임상 데이터와 모의실험 데이터를 비교하여 평가되었다. 다양한 수술 전 추궁각에서 개방문 추궁성형술과 양문 추궁성형술을 모의실험하여 척추관 넓이의 확장을 측정하였다.

결과

임상 데이터와 모의실험으로 얻은 데이터를 비교하였을 때 유의한 차이가 없었고 ($p > 0.05$), 매우 높은 상관관계 ($p < 0.001$)를 보였다. 수술 전 추궁 각도가 32° 이하일 때에는, 척추관 면적의 증가는 개방문 추궁성형술의 경우가 양문 추궁성형술보다 유의하게 더 컸다. 그러나 수술 전 추궁 각도가 33° 이상일 때에는, 척추관 면적의 증가는 양문 추궁성형술의 경우가 개방문 추궁성형술보다 유의하게 더 컸다.

결론

수술 전 추궁 각도가 32° 이하일 때에는, 개방문 추궁성형술이 척추관 면적이라는 측면에 있어서 유리하다.

주요어: 개방문 추궁성형술, 양문 추궁성형술, 추궁각, 척추관 확장
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