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ORIGINAL PAPER
PŮVODNÍ PRÁCE

Three-Dimensional Computed Tomography Image Reformation for Comparison of Foraminal Cross-Sectional Dimension in Patients Who Have Undergone Laminoplasty and Laminectomy with Fusion

Úprava obrazu trojrozměrné počítačové tomografie pro srovnání rozměru průsvitu intervertebrálního foramen u pacientů, kteří podstoupili laminoplastiku a laminektomii s fúzí

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ABSTRACT

PURPOSE OF THE STUDY

Laminectomy with fusion (LF) is commonly performed with laminoplasty (LP) for cervical myelopathy. Foraminal stenosis is important in the surgical treatment of cervical myelopathy. LF and LP can affect foraminal size in different ways. This study aimed to compare foraminal dimensions after LF and LP using a medical computer-assisted design (CAD) program.

MATERIAL AND METHODS

Computed tomography (CT) scans of the cervical vertebrae of 16 patients with cervical myelopathy were retrospectively viewed in the Digital Imaging and Communications in Medicine format on a CAD program. CT images were reformatted in an oblique plane perpendicular to the long axis of each foramen from C2–C3 to C6–C7. The narrowest foraminal cross-sectional dimension (FCD) was measured and compared between the LF and LP groups at the operated, non-operated, and C4–C5 levels. The difference between the preoperative and postoperative FCDs was also calculated and compared between the operated and C4–C5 levels. Intra- and interobserver reliabilities for FCD measurements were evaluated using intraclass correlation coefficients.

RESULTS AND DISCUSSION

At the operated spinal levels, the LF and LP groups showed decreased and increased mean FCDs, respectively. At the adjacent non-operated levels, the mean FCD slightly increased in both the groups. In the LF group, the difference between the preoperative and postoperative FCDs in the C4–C5 levels was larger than that in the other operated levels, but this difference was insignificant.

CONCLUSIONS

LF and LP showed contrary results for FCD. Therefore, FCD and kyphosis should be considered for LF and LP.

Key words: three-dimensional, foraminal cross-sectional dimension, laminoplasty, laminectomy fusion, computer-aided design, drafting system, preoperative–postoperative comparison.

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INTRODUCTION

Foraminal stenosis is a factor considered in the surgical treatment of cervical myelopathy. Particularly, C5 palsy after posterior decompression in cervical surgery is a constant challenge for spine surgeons, with an incidence ranging from 3% to 14% (3, 10, 18). Many authors have commented on the risk factors for C5 palsy, including ossification of the posterior longitudinal ligament, narrower intervertebral foramen, excessive spinal cord drift, and male sex (3). Furthermore, the etiology of C5 palsy has been described as a preexisting pathology of the C5 root (6), iatrogenic injury (13), tethering effect of surgery (19), and ischemic changes in the spinal cord (12). However, the cause of postoperative C5 palsy remains unclear. When comparing laminectomy with fusion (LF) and laminoplasty (LP), palsy is considered more common in patients with LF than in those with LP (3, 4, 7, 18). We focused on the different characteristics of the two techniques, i.e., the tendency for postoperative lordosis (8) and fixed foraminal space after LF. LF maintains fixed lordosis, whereas after LP, patients can have a comfortable posture between lordosis and kyphosis by a compensatory mechanism. We hypothesized that postoperative changes in the foraminal dimension in patients who underwent LF were different from those in patients who underwent LP because the foraminal dimension after LF was fixed. In contrast, LP can still provide compensation widening of the foraminal dimension; however, regular computed tomography images do not offer accurate measurements owing to preset imaging acquisition parameters. There is, therefore, the need for more accurate measurement methods. Hence, this study aimed to compare the change in foraminal cross-sectional dimension (FCD) after LF and LP using a medical computer-assisted design (CAD) program.

MATERIAL AND METHODS

The study procedures were performed in accordance with the Declaration of Helsinki and its later amendments. The study was approved by the Institutional Review Board (approval number 2018-01-009) of our hospital before collecting patient data. The requirement for informed consent was waived because of the retrospective nature of this study.

Patient data

Patients who underwent preoperative and postoperative CT after LF or LP during 2012–2016 were retrospectively evaluated. A total of 16 patients were included in the study. The LP and LF groups included 10 and 6 patients with cervical myelopathy, respectively. Patients' demographic data, including age and sex, were recorded.

FCD measurement

The cervical vertebral CT scans of 16 patients were viewed in the Digital Imaging and Communications in Medicine format using the Mimics Suites software (Materialise, Version 19.0, Leuven, Belgium). CT images were reformatted in the oblique plane perpendicular to the long axis of each foramen from C2–C3 to C6–C7, with a thickness of 1 mm. The narrowest FCD was measured (Figures 1 and 2).

Lordosis measurement

The Cobb angle was measured at the operated levels to evaluate pre- and postoperative lordosis (11).

Statistical analyses

Comparison of demographics between the LP and LF groups

The age and sex distributions in the LF and LP groups were compared using the Wilcoxon rank-sum test for continuous variables (age) and Fisher's exact test for categorical variables (sex).

Comparison of preoperative and postoperative FCDs and differences in FCD

Data were classified into operated, C4–C5, and non-operated adjacent segments. Preoperative and postoperative FCDs were compared among the three groups. The differences in FCD (DFCD) between the preoperative and postoperative FCDs at the operated levels, C4–C5 segment, and non-operated levels were compared

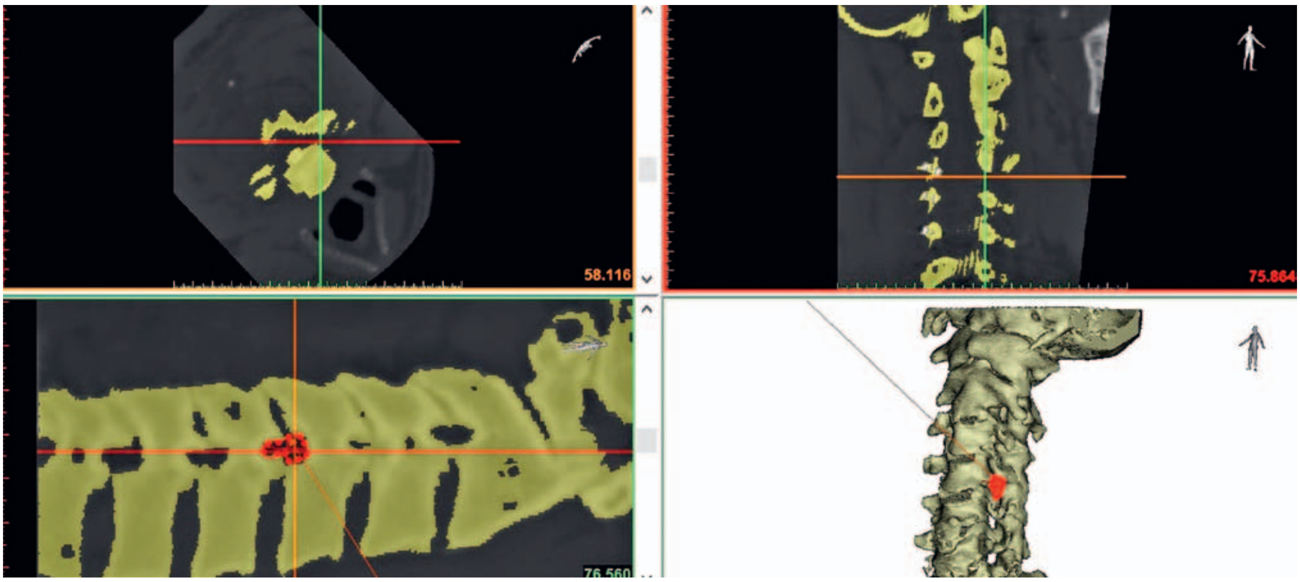

Fig. 1. Reconstructed computed tomography scan: Cervical spine computed tomography scans reconstructed in the oblique plane viewed in Digital Imaging and Communications in Medicine format.

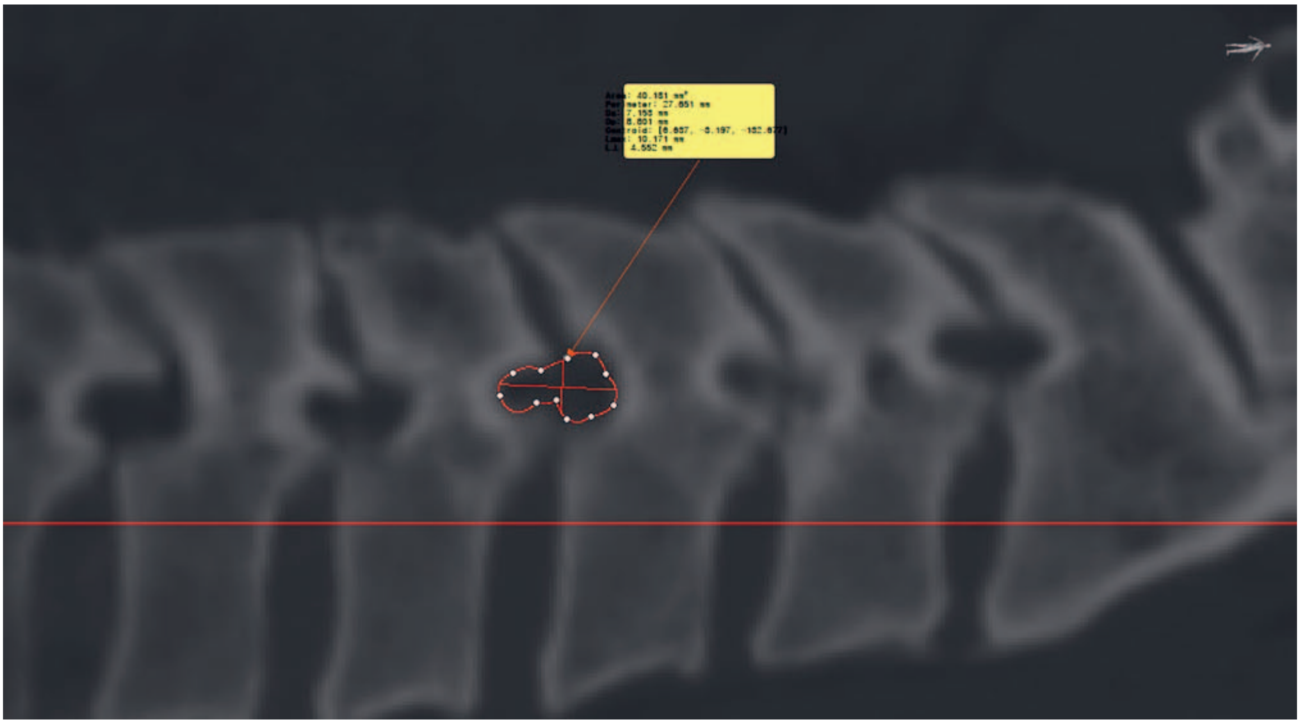

Fig 2. Foraminal cross-sectional dimension area: The lowest foraminal cross-sectional dimension area was measured in the resliced oblique image.

for the LF and LP groups. This comparison was also performed for the DFCD between the operated and non-operated levels. Comparison of the preoperative and postoperative FCDs and of the segment groups was performed using a t-test or Wilcoxon rank-sum test. SAS v.9.4 (SAS Institute Inc., Cary, NC, USA) was used for statistical analyses.

Intra- and interobserver reliability test

For measurement reliability, the interobserver error was calculated for 22 foramina using the intraclass correlation coefficient (ICC), and the intraobserver error was assessed using the ICC for 22 foramina selected for a second examination. For the interpretation of the ICC of the inter-rater agreement measurement, the following standard was used: <.40, poor; .40–.59, fair; .60–.74, good; and .75–1.00, excellent. Raters 1 (LSJ) and 2 (LHJ) were independent orthopedic spine consultants with >5 years of clinical experience.

Preoperative and postoperative lordosis comparison

Preoperative and postoperative lordosis angles were compared using the Wilcoxon signed-rank test.

RESULTS

The demographic data of both groups are shown in Table 1. No significant differences in age and sex distributions were found between the two groups. In total, 60 and 100 foramina were evaluated in the LF and LP groups, respectively. At the operated spinal levels, including the C4–C5 level, the mean FCD was lower in the LF group and higher in the LP group. At the non-operated levels, FCD increased minimally in both groups. However, these changes were not significant. The other detailed data are presented in Table 2.

When the DFCD was compared between the C4 and C5 segment groups and the other operated levels in the LF and LP groups, the mean DFCD at the C4–C5 segments was larger than at other spinal levels. However, this difference was not significant (p = .092 in the LF group and p = .118 in the LP group; Table 3). Significant differences were found between the DFCD at the operated and non-operated levels (Table 4).

The inter- and intra-rater reliabilities (i.e., ICCs) were excellent (.797–.970) for raters 1 (.927) and 2 (.881).

The mean lordosis angle changed from 6.5° to −2.6° (p = .027) in the LP group and from 4.8° to 8.6° (p = .062) in the LF group. For one case in the LP group, lordosis increased from 2.9° to 13.0°. for other cases in the LP group, lordosis decreased. For one case in the LF

Table 1. Demographic data for the laminectomy with fusion and laminoplasty groups

	LF	LP	p-value
	n = 6	n = 10	
Age (years)	69.0 ± 6.0	62.5 ± 10.5	.174
Male (number, %)	6 (100%)	9 (90%)	>.999
Female (number, %)	0 (0.0%)	1 (10%)	

p-values are calculated using the Wilcoxon rank-sum test and Fisher's exact test for continuous (age) and categorical (sex) variables, respectively.
LF, laminectomy with fusion; LP, laminoplasty.

Table 2. Preoperative and postoperative foraminal dimension areas in patients who underwent laminectomy with fusion and laminoplasty

		Laminectomy with fusion (mm^2)			Laminoplasty (mm^2)			*p*-value*
		Pre	Post	Difference	Pre	Post	Difference	
		n = 12			n = 20			
C4–C5	mean ± SD	28.5 ± 6.4	25.4 ± 5.9	–3.1 ± 3.1	33.3 ± 8.0	35.8 ± 8.1	2.6 ± 3.4	<0.001
	min	19.4	16.3	–10.5	20.5	21.3	–1.2	
	median	28.6	26.9	–2.8	32.5	34.8	1.5	
	max	39.3	33.6	3.0	52.6	52.4	12.0	
		n = 42			n =56			
Levels with operation	mean ± SD	29.4 ± 9.9	27.1 ± 10.0	–2.3 ± 2.3	32.4 ± 8.8	34.0 ± 9.2	1.6 ± 2.7	<0.001
	min	18.4	16.3	–10.5	17.8	18.4	–2.6	
	median	26.8	24.3	–1.8	32.0	33.0	0.9	
	max	73.3	72.5	3.0	57.4	59.6	12.0	
		n = 18			n = 44			
Adjacent level	mean ± SD	35.1 ± 11.6	35.7 ± 11.3	0.6 ± 4.1	40.1 ± 11.4	40.3 ± 11.1	0.2 ± 2.2	0.0084
	min	16.5	23.3	–12.1	16.2	17.1	–5.9	
	median	34.4	31.3	1.1	39.5	39.3	0.4	
	max	57.5	58.4	6.7	65.9	66.2	5.1	

* Comparisons of preoperative and postoperative differences between the two groups were examined using the t-test or Wilcoxon rank-sum test. SD, standard deviation

Table 3. Mean foraminal cross-sectional dimension at the C4–C5 segments and other operated levels

	Other operated levels (mean ± SD)			**C4–C5** (mean ± SD)			p-value*
	Pre	Post	Post – Pre	Pre	Post	Post – Pre	
LP	n = 36			n = 20			0.118
	32.0 ± 9.3	33.0 ± 9.6	1.0 ± 2.2	33.3 ± 8.0	35.8 ± 8.4	2.6 ± 3.4	
LF	n = 30			n = 12			0.092
	29.8 ± 11.1	27.9 ± 11.3	–1.9 ± 1.9	28.5 ± 6.4	25.4 ± 5.9	–3.1 ± 3.1	

* Comparisons of differences (= Post – Pre) between the two operation groups were assessed using the t-test or Wilcoxon rank-sum test. LF, laminectomy with fusion; LP, laminoplasty; SD, standard deviation.

Table 4. Mean foraminal cross-sectional dimension at the operated and non-operated levels

	All operated levels (mean ± SD)			**Non-operated levels** (mean ± SD)			p-value*
	Pre	Post	Post – Pre	Pre	Post	Post – Pre	
LP	n = 56			n = 44			0.010
	32.4 ± 8.8	34.0 ± 9.2	1.6 ± 2.7	40.1 ± 11.4	40.3 ± 11.1	0.2 ± 2.2	
LF	n = 42			n = 18			< 0.001
	29.4 ± 9.9	27.1 ± 10.0	–2.3 ± 2.3	35.1 ± 11.6	35.7 ± 11.3	0.6 ± 4.1	

* Comparisons of differences (= Post – Pre) between the two operation groups were assessed using the t-test or Wilcoxon rank-sum test. LF, laminectomy with fusion; LP, laminoplasty; SD, standard deviation.
LF, laminectomy with fusion; LP, laminoplasty; SD, standard deviation.

group, lordosis decreased from 5.0° to 3.3°. For other cases in the LF group, lordosis increased.

DISCUSSION

This study examined the narrowest FCD change in the cervical foramina after LF and LP and evaluated the differences between the two surgery groups. Previous studies have reported more cases of C5 palsy with LF than with LP (2,7,9). Since the etiology of C5 palsy after cervical surgery is still not entirely clear, it is difficult to state the reasons for this trend in LF. We focused on the foraminal size before and after surgery. Our hypothesis was proven by our findings that FCD decreased postoperatively in the LF group and increased in the LP group at the operated levels. Moreover, the mean DFCD tended to increase at the C4–C5 level more than at the other operated levels (p = .09).

As Shinomiya et al. (15) described, short C5 ventral rootlets seem to be tauter and easily injured. We postulated that the decrease in foramen size could negatively affect the already taut C5 root by exerting more pressure. Another explanation for C5 palsy is that the narrowly fixed foraminal dimension of the LF can increase the risk of palsy. Previous *in vivo* and *in vitro* studies have demonstrated that flexion causes foraminal widening and extension, which causes foraminal narrowing (2, 5). Furthermore, Abola et al. (1) have described that the foraminal area at C4/5 and C5/6 are significantly smaller than at C6/7. In patients with LF, this compensatory mechanism of increasing the foramen by changing the neck position is unavailable at the operated level. In other words, this compensatory mechanism may be due to postoperative kyphosis after LP. However, the adjacent levels showed increased FCD, which explains the compensation mechanism maintained at adjacent levels.

Although we found that decreases in FCD were significant at the operated level in the LF group, our results cannot explain all cases of C5 palsy. Several other possible risk factors have been described previously (3, 6, 12, 13, 19). We still need to consider other factors, such as cord deviation and iatrogenic injuries. A narrow FCD does not necessarily correlate with C5 palsy. Suk et al. described a change in the foraminal dimension in patients with foraminal stenosis after anterior cervical discectomy and fusion (ACDF) (17). As increased segmental lordosis was negatively correlated with foraminal dimension (17), surgeons must remember that the FCD can become narrower after LF when planning a surgical approach. Thus, additional foraminotomy or ACDF should be considered, and the height of the disc should be maintained.

In this study, we used a medical CAD program to reflect the narrowest dimension. Measuring FCD on conventional CT may not reflect the actual situation. Roberts et al. showed good interobserver variability and high observer confidence in measuring the foramina and recommended oblique reformation with a CT scan (11). The method used in our study measured each foramen individually. Retrospective oblique reconstruction was performed using a medical CAD program. Simpson et al. showed different optimal viewing angles for the cervical foramen (19), indicating that uniform CT sections cannot represent the actual foraminal dimension area. Kitagawa et al. (5) used an on-site oblique CT reconstruction to measure each foramen. However, on-site reconstruction can only be performed prospectively. Using medical CAD systems, we retrospectively analyzed the foraminal dimensions.

This study had several limitations. First, selection bias was caused by only including patients who underwent preoperative and postoperative CT. Second, the method used to measure FCD was not completely objective. A long axis should be drawn intuitively in the axial section, and the dimension area should be measured within the sectioned views. However, our method has greater reliability than other methods, such as measurement on conventional sagittal CT in an axial or three-dimensional view (16), and showed excellent inter- and intra-rater reliabilities. Third, we did not correlate FCD with the clinical outcomes. In the selected patients, C5 palsy did not occur after surgery. Finally, we only had a few patients for lordosis evaluation and our study did not contain clinical outcome. These limitations could be addressed in future studies involving a large number of patients. Nonetheless, even though could not clearly conclude on a correlation between foraminal narrowing and clinical outcomes, the clear tendency of foraminal dimension change should be noticed by spine surgeons.

CONCLUSIONS

LF and LP showed contrary results regarding FCD and postoperative loss of lordosis. When performing LF, decreased FCD should be considered, and additional foraminotomy or ACDF should be performed. Similarly, when performing LP, postoperative kyphosis should be considered.

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