Simple presurgical method of predicting C5 palsy after cervical laminoplasty using C5 nerve root ultrasonography

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OBJECTIVE The incidence of C5 palsy after cervical laminoplasty is approximately 5%. Because C5 palsy is related to cervical foraminal stenosis at the C4–5 level, the authors hypothesized that cervical foraminal stenosis can be diagnosed by examining the C5 nerve root (NR) using ultrasonography. The purpose of this study was to investigate whether postoperative C5 palsy could be predicted using ultrasonography.

METHODS This study used a prospective diagnosis design. In total, 140 patients undergoing cervical laminoplasty were examined with ultrasound. The cross-sectional area (CSA) of the C5 NR was measured on both sides before surgery, and the incidence of postoperative C5 palsy was examined. The difference between the CSA of the patients with and without C5 palsy and the lateral differences in the C5 palsy group were determined.

RESULTS The incidence of C5 palsy was 5% (7 cases). Symptoms manifested at a median of 5 days after surgery (range 1–29 days). The CSA of the C5 NR on the affected side was significantly enlarged in the C5 palsy group compared with that in the no-C5 palsy group ($p = 0.001$). In addition, in the patients who had C5 palsy, the CSA of the C5 NR was significantly enlarged on the affected side compared with that on the unaffected side ($p = 0.02$). Receiver operating characteristic analysis indicated that the best threshold value for the CSA of the C5 NR was 10.4 mm², which provided 91% sensitivity and 71% specificity.

CONCLUSIONS C5 palsy may be predicted preoperatively using ultrasound. The authors recommend the ultrasonographic measurement of the CSA of the C5 NR prior to cervical laminoplasty.

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KEYWORDS C5 nerve root; C5 palsy; foraminal stenosis; ultrasonography; cervical laminoplasty

THE incidence of C5 palsy after cervical laminoplasty is approximately 5%.^{3,6,10,14} C5 palsy can be caused by cervical foraminal stenosis,^{8,9} reperfusion syndrome,⁵ spinal cord shift,¹⁶ or heat injury.⁷ Particularly in cases of cervical foraminal stenosis, some reports have described presurgical predictive methods: thin-slice CT⁸ and various MRI methods (oblique MRI¹² or MR myelography²) to avoid C5 palsy after cervical laminoplasty. It is probable that cervical foraminal stenosis contributes to C5 palsy after cervical laminoplasty. However, the reliability

of evaluations remains unclear because MRI and CT scans often show multilevel compression.

Some recent reports have indicated that cervical foraminal stenosis is related to an enlarged cervical nerve root (NR) at the same level on the affected side and that this enlarged cervical NR might be detectable with ultrasonography.^{11,19} Moreover, 3D MRI has revealed that at the lumbar level, NRs entrapped by foraminal stenosis become swollen.⁴

We hypothesized that C5 palsy could be predicted by

ABBREVIATIONS CSA = cross-sectional area; CSM = cervical spondylotic myelopathy; NR = nerve root; JOA = Japanese Orthopaedic Association; MMT = manual muscle test; OPLL = ossification of the posterior longitudinal ligament; ROC = receiver operating characteristic; TP = transverse process.

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examining the C5 NR using cervical ultrasonography before cervical laminoplasty.

Methods

The institutional review board of Aichi Medical University Hospital approved this study, and informed consent was obtained from all participating patients. This prospective cohort study was performed between December 2014 and April 2017 at our hospital and included patients with cervical spondylotic myelopathy (CSM).

Inclusion and Exclusion Criteria

First, the patients who were eligible for inclusion suffered from CSM symptoms in the arm, hand, or finger, including paresthesias, numbness and sensory changes, weakness, or abnormal deep tendon reflexes. Second, the patients were required to have undergone a cervical MRI that revealed cervical osteophytes, ossification of the posterior longitudinal ligament (OPLL), and cervical disc herniation that compressed the cervical spinal cord. Third, patients who were going to undergo cervical laminoplasty of at least the C4 and C5 levels were included. The surgical procedure used for the cervical laminoplasty, such as the open door or French door method, was selected by the spine surgeon.

Patients were excluded if they had experienced 1) cervical radiculopathy only; 2) neck pain only; 3) deltoid muscle weakness; 4) severe diabetes, renal, or liver dysfunction; 5) myopathy, neuropathy, or collagen diseases; 6) trauma; or 7) additional posterior cervical fusions. Among the 160 patients who were considered for enrollment in the study, 147 met the baseline inclusion criteria. However, an additional 7 patients were excluded because clear ultrasonography images could not be obtained before the cervical laminoplasty. In total, data from 140 patients were included in the analysis (Fig. 1). Postoperative C5 palsy was defined as the presence of deltoid muscle weakness of grade 3 or less, according to a manual muscle test (MMT) with or without biceps weakness.

Surgical Procedure

The open door or the French door laminoplasty method was performed with the patient in the prone position under general anesthesia. During exposure of the cervical spine, the spinal processes were split at the midline and cut at the base. In the open door method, a right-side gutter was made and used as a hinge at the lateral border of the laminae, and a left-side gutter on the contralateral side was produced as an open side. The open side of the lamina was lifted and fixed with hydroxyapatite spacers (HOYA Technosurgical Co. Ltd.) and nylon sutures. In the open door method, the laminae were split at the midline using a surgical drill. Bilateral gutters were created as hinges at the lateral border of the laminae. The treated laminae were elevated like a French door and then fixed with the hydroxyapatite spacers. Foraminotomy was not performed in all cases.

Radiological Evaluation

Cervical alignment of the C2–C7 Cobb angle was de-

termined on preoperative standing lateral radiographs obtained in neutral, flexion, and extension positions. OPLL was diagnosed on CT scans. High T2 signal intensity at C3–4 or C4–5 was determined on the basis of preoperative MRI.

Ultrasonography Measurements

Four musculoskeletal ultrasound experts who each had more than 5 years of experience performed ultrasonography using a real-time scanner with a 13–5 MHz linear array probe before cervical laminoplasty. These individuals were blinded to the patients' clinical characteristics or radiological findings.

For the ultrasound examination, the patients were placed in a lateral decubitus position.¹⁸ The examiners set the ultrasound linear array probe to the brightness mode and stood behind the subject during the examination. They investigated the C5, C6, and C7 NRs bilaterally on an axial image by perceiving the cervical transverse process (TP) form. The C5 and C6 TPs have obvious anterior and posterior tubercles. In contrast, the C7 TP has an unremarkable anterior tubercle and a prominent posterior tubercle. Thus, the C7 TP is an important landmark.¹⁷

The examiners measured the cross-sectional area (CSA, in mm²) of the bilateral C5 NRs.

The C5 NR measurement point was standardized. The CSA of the C5 NR was measured where the examiners found the C5 NR between the anterior and posterior tubercles of the TP.

We assessed 4 components: 1) The affected CSAs of the C5 NR of the subjects with postoperative C5 palsy (C5 palsy group) were compared with those of the subjects in the group without C5 palsy (no-C5 palsy group). 2) The difference between the CSA of the affected C5 NR and the unaffected C5 NR was calculated in the C5 palsy patients. 3) The risk factors for C5 palsy were examined using multivariate logistic regression analyses. 4) The sensitivity, specificity, and cutoff values of the CSA of the C5 NR were investigated for the C5 palsy and no-C5 palsy groups.

Sample Size

Based on a previously published pilot study performed by our group,¹⁷ we estimated that patients with symptomatic C5 NR foraminal stenosis would have a CSA of the C5 NR of 14.2 ± 3.1 mm² compared with a CSA of 6.4 ± 1.7 for those without C5 NR foraminal stenosis.¹⁹ Assuming a 5% postoperative C5 palsy rate, we determined that we needed a sample size of 140 patients (of which 7 were likely to develop C5 palsy) in order to achieve an alpha of 0.05 and a power of 0.80.

Statistical Analysis

The baseline characteristics of various factors were compared between the C5 palsy and no-C5 palsy groups using t-tests or chi-square tests. Multivariate logistic regression analyses were used to explore the risk factors for C5 palsy after cervical laminoplasty. The receiver operating characteristic (ROC) curve was used to examine the sensitivity, specificity, and cutoff values of the CSA for the

FIG. 1. Flow diagram showing patient selection for this study. In the 6 cases in which patients were excluded due to ultrasonography not being performed, the reasons were as follows: in 4 cases, the patients forgot the ultrasonography appointment after they had been enrolled in the study; in the remaining 2 cases, the ultrasonography examination was not performed due to a scheduling omission.

C5 NR. Intraclass correlation coefficients of ultrasound measurements for the 4 examiners were calculated based on examinations they each performed on 5 normal volunteers. Data were analyzed using SPSS software (version 22; IBM Corp.). The significance level was set to 0.05.

Results

The incidence of C5 palsy was 5% (7 of 140 patients). The timing of the initial manifestation of C5 palsy ranged from 1 to 29 days (median 5 days) after surgery. The baseline characteristics of the no-C5 palsy group (133 patients, including 89 men and 44 women; mean age 67 years) and

the C5 palsy group (7 patients, including 4 men and 3 women; mean age 63 years) are presented in Table 1. The 2 groups did not differ significantly in terms of age, symptom duration, sex, diabetes status, smoking status, Japanese Orthopaedic Association (JOA) score, radiographic assessments, MRI findings, or surgical methods (Table 1).

On the cervical ultrasound, the CSA of the C5 NR was significantly enlarged on the affected side in the C5 palsy group ($10.8 \pm 4.2 \text{ mm}^2$) compared with that in the no-C5 palsy group ($7.1 \pm 2.3 \text{ mm}^2$) ($p = 0.001$). However, there was no significant between-groups difference with respect to the CSA of the C5 NR on the unaffected side (Figs. 2 and 3).

TABLE 1. Baseline characteristics

Characteristic	No C5 Palsy (n = 133)	C5 Palsy (n = 7)	Difference (95% CI)	p Value
Mean age in yrs	67 $\pm$ 11	63 $\pm$ 14	4.0 (−4.5 to 13)	0.3
Mean duration of CSM Sx in mos	12 $\pm$ 11	12 $\pm$ 9	0.6 (−9.3 to 8.1)	0.9
Sex, n				0.7
Male	89	4		
Female	44	3		
Diabetes, n (%)	34 (26)	1 (14)		0.7
Smoking, n (%)	36 (27)	2 (29)		0.1
Mean JOA score	10.7 $\pm$ 2.6	11.2 $\pm$ 2	0.5 (−2.5 to 1.5)	0.6
Imaging findings				
Cobb angle				
Neutral	10.5° $\pm$ 13.8°	12.3° $\pm$ 11.4°	1.7° (−12.2° to 8.7°)	0.7
Flexion	−11.9° $\pm$ 15°	−8.9° $\pm$ 8.8°	3° (−14.3° to 8.3°)	0.6
Extension	25° $\pm$ 36.5°	27.7° $\pm$ 10°	2.8° (−30° to 24.6°)	0.8
OPLL, n (%)	20 (15)	1 (14)		1
High T2 signal intensity at C3–4 or C4–5, n (%)	37 (28)	2 (29)		1
Surgical method, n				
Open door	51	3		
French door	82	4		

Sx = symptoms.

FIG. 2. C5 NR ultrasonography. **A:** The CSA of the C5 NR (arrow) in the C5 palsy group. **B:** The CSA of the C5 NR (arrowhead) in the no-C5 palsy group. The asterisks (*) indicate the anterior tubercle of the C5 transverse process. The double asterisks (**) indicate the posterior tubercle of the C5 transverse process.

In the C5 palsy group, the CSA of the C5 NR was significantly greater on the affected side ($10.8 \pm 4.2 \text{ mm}^2$) than on the unaffected side ($6.3 \pm 1.9 \text{ mm}^2$) ($p = 0.02$) (Figs. 2 and 3).

Multivariate logistic regression analyses of the C5 palsy group after cervical laminoplasty indicated that enlargement of the CSA of the C5 NR was a risk factor ($B = 0.5$, OR 1.6, 95% CI 1.2–2.3, $p = 0.005$) (Table 2).

Table 3 presents the threshold values of the CSA of the C5 NR obtained using ROC analysis. The best threshold value for the C5 NR was 10.4 mm^2 (CSA), with 91% sensitivity and 71% specificity. The area under the curve for the CSA was 0.79 (95% CI 0.59–0.98).

The interrater reliability of the CSA measurements was 0.71 (95% CI 0.49–0.85). Moreover the intrarater reliability ratings of the 4 examiners were 0.71 (95% CI 0.37–0.87), 0.61 (95% CI 0.1–0.83), 0.71 (95% CI 0.33–0.87), and 0.74 (95% CI 0.4–0.89).

Discussion

This prospective study investigated the CSA of the C5 NR using cervical ultrasonography. We hypothesized that enlargement of the C5 NR before cervical laminoplasty might result in C5 palsy. The investigation was

FIG. 3. The CSA of the C5 NR was compared between the C5 palsy and no-C5 palsy groups. *Comparison of the CSA of the C5 NR on the affected side ($10.8 \pm 4.2 \text{ mm}^2$) vs the unaffected side ($6.3 \pm 1.9 \text{ mm}^2$) in the C5 palsy group ($p = 0.02$). **Comparison of the CSA of the C5 NR of the affected side of the C5 palsy group ($10.8 \pm 4.2 \text{ mm}^2$) vs the no-C5 palsy group ($7.1 \pm 2.3 \text{ mm}^2$) ($p = 0.001$). †Comparison of the CSA of the C5 NR on the unaffected side in the C5 palsy group ($6.3 \pm 1.9 \text{ mm}^2$) vs the no-C5 palsy group ($7.1 \pm 2.3 \text{ mm}^2$) ($p = 0.3$).

accomplished by comparing the preoperative CSA of the C5 NR in patients who subsequently developed C5 palsy to measurements obtained in patients who did not develop C5 palsy. We obtained 3 important findings from this study. First, we determined that the threshold value of the C5 NR was 10.4 mm^2 (CSA), with 91% sensitivity and 71% specificity. Second, the CSA of the affected C5 NR in the C5 palsy group was significantly larger than both the CSA of the C5 NR in the no-C5 palsy group and the CSA of the unaffected C5 NR in the C5 palsy group. Third, enlargement of the CSA of the C5 NR was confirmed as a risk factor for C5 palsy after cervical laminoplasty.

Previous reports have observed a relationship between cervical foraminal stenosis at the C4–5 level and C5 palsy after cervical laminoplasty.^{8,9} Recent articles have report-

TABLE 2. Multivariate logistic regression analyses of the risk factors for C5 palsy after cervical laminoplasty

Variable	B	OR (95% CI)	p Value
Sex	0.4	1.4 (0.2–9.9)	0.7
Age	0.01	0.9 (0.9–1)	0.1
Diabetes	−0.1	0.9 (0.1–8.8)	0.9
Smoking	−0.1	0.8 (0.1–6.5)	0.9
CSA of C5 NR	0.5	1.6 (1.2–2.3)	0.005
OPLL	0.6	1.8 (0.1–22)	0.6
High T2 signal intensity at C3–4 or C4–5	−0.4	0.7 (0.1–6.5)	0.7

OR = odds ratio.

TABLE 3. Sensitivity and specificity of CSA for diagnosing C5 palsy

Threshold	Sensitivity	Specificity	LR+	LR-	AUC (95% CI)
5.7 mm ²	30%	100%		0.7	
7.7 mm ²	41%	86%	2.9	0.7	
10.4 mm ²	91%	71%	3.1	0.1	
14.2 mm ²	99.2%	14%	1.2	0.1	0.79 (0.59–0.98)

AUC = area under the curve; LR- = negative likelihood ratio; LR+ = positive likelihood ratio.

ed that cervical foraminal stenosis led to swelling of the cervical NR at the affected level that could be detected with ultrasonography.^{11,19} Thus, cervical laminoplasty for patients with a swollen C5 NR may result in postsurgical C5 palsy. It was clear that postsurgical C5 palsy occurred in the patients with a swollen C5 NR.

Cervical nerve enlargement is believed to be caused by a relationship between entrapment neuropathy and focal vascular impairment. A report has demonstrated that external entrapment of a peripheral nerve leads to changes of internal construction in entrapment diseases and that deteriorated venous perfusion leads to increased reversible intraneural edema and intraneural pressure.¹ Another study has also demonstrated that increased permeability was exhibited within the compressed nerve root in entrapment neuropathies. The compressed nerve root leads to fibrosis and secondary chronic edema.¹⁵ Therefore, patients with cervical foraminal stenosis presented with an enlarged C5 NR because of C5 NR entrapment at the C4–5 level, and after cervical laminoplasty, the kink in the C5 NR became more severe in association with the posterior shift of the spinal cord, thereby leading to C5 palsy.

A systematic review article has reported the following as risk factors for postsurgical C5 palsy: advanced age, sex, OPLL, high T2 signal in the spinal cord, and cervical foraminal stenosis.^{3,6} In our study, an enlarged C5 NR indicative of cervical foraminal stenosis was the only identified risk factor. We consider our results to be compatible with those of various previous reports.

Our results show that if the laminoplasty was performed in the patients with CSM and an enlarged C5 NR, the risk of postsurgical C5 palsy was high. Thus, we recommend that in such cases the surgical procedure should be changed to anterior decompression and fusion or be performed in combination with posterior foraminotomy.

Limitations

This study has some limitations. First, cervical ultrasonographic examination is not currently in use worldwide. Nevertheless, ultrasonography is a simple examination that is widely performed for the thyroid, heart, liver, or abdominal regions, and we believe that cervical ultrasonography will be a popular examination in the future. Second, patients who underwent posterior decompression with fusion were excluded. Posterior fusion surgery increases the likelihood of C5 palsy (reported rate of 11%) because of iatrogenic postsurgical foraminal stenosis due to the correction of cervical alignment.¹³ Because the preopera-

tive CSA of the C5 NR may be normal in these cases, our technique would not be expected to be reliable for predicting postoperative C5 palsy in patients undergoing fusion surgery.

Conclusions

A diagnostic threshold with high sensitivity and specificity was identified for the CSA of the C5 NR associated with C5 palsy. We recommend ultrasonographic measurement of the CSA of the C5 NR before performing cervical laminoplasty.

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Conception and design: Takeuchi. Acquisition of data: Takeuchi, Wakao, Kamiya, Hirasawa. Analysis and interpretation of data: Takeuchi, Kamiya, Murotani. Drafting the article: Takeuchi, Wakao. Critically revising the article: Takeuchi, Wakao. Reviewed submitted version of manuscript: Takeuchi. Approved the final version of the manuscript on behalf of all authors: Takeuchi. Statistical analysis: Murotani. Administrative/technical/material support: Wakao, Kamiya. Study supervision: Takayasu.

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