Analysis of Factors Affecting the Clinical Course in C5 Palsy: A Korean Cervical Spine Study Group (KCSSG) Multicenter Cohort Study

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Research Article

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Abstract

The development of C5 palsy is a serious, well-documented complication after cervical spine surgery. Therefore, a more precise and extensive analysis of C5 palsy is required. The present study aimed to evaluate the characteristics and clinical course of C5 palsy using a Korean Cervical Spine Study Group (KCSSG) database. A retrospective review of clinical and radiological data was performed for 85 patients who had C5 palsy. We investigated multiple clinical factors [main pathology, pre-operative symptoms, surgical method, symptom duration, operation method, side of C5 palsy, C5 palsy grade and onset time, course of recovery from C5 palsy, and Japanese Orthopedic Association score] and radiological factors [C4–5 foramen diameter, occupying ratio, T2HIZ (high intensity zone in T2 weighted magnetic resonance image)] . On multivariate analysis, old age (OR 12.73 [95% CI 1.1-147.37]), posterior approach (OR 39.16 [95% CI 2.24-682.31]), radiculopathy (OR 13.5 [95% CI 1.06-171.2]), OPPLL(OR 13.7 [95% CI 1.33-140.77]), C2-7 angle (pre-OP; OR 0.83 [95% CI 0.71-0.98], post-OP; OR 1.26 [95% CI 1.03-1.53]) were the predictor for early onset of C5 palsy. Small dimension of C4-5 foramen (OR 0.58 [95% CI 0.37-0.92]) and less degree of cord rotation (pre-OP, OR 0.83 [95% CI 0.72-0.96]), were the predictor for severe status of C5 palsy. The clinical course of C5 palsy (onset and severity) was influenced by age, pre-operative symptom, surgical approach, main pathology, C2-7 angle, T2HIZ grade, pre-operative cord rotation and C4-5 foramen diameter.

Introduction

The development of C5 palsy (deltoid muscle paralysis) is a serious, well-documented complication after cervical spine surgery. Although the incidence of post-operative C5 palsy varies from report to report, it is generally thought to occur in approximately 5-6 % of cervical spine surgery patients. Several hypotheses have been proposed for C5 palsy, along with predisposing risk factors. Previous research has provided useful information and generated a reasonable C5 palsy pathophysiology through a systematic and scientific approach. However, the detailed pathophysiology and clinical course of C5 palsy remains poorly understood and inconclusive.

Generally, the clinical course of C5 palsy may not be uniform, but rather diverse and dynamic. In this situation, it may be very valuable to attempt to analyze various clinical and radiological factors that affect the clinical course of C5 palsy. Therefore, The Korea Cervical Spine Study Group (KCSSG) decided to collect as many C5 palsy cases as possible to conduct a precise analysis with a wide scope through a large number of C5 palsy cases. The purpose of the present study was to investigate relevant factors that affect the clinical course of C5 palsy by analyzing a large number of C5 palsy patients in cervical spine surgery.

Materials And Methods

Patient population

We conducted a multicenter retrospective review of patients who developed C5 palsy after cervical spine surgery. Eighty-five patients (66 males and 19 females; mean age, 61.2 years) were enrolled in this study from fifteen medical centers (14 academic institutions, one private institution) in the KCSSG between January 2012 and December 2016. We excluded cases, which were related to tumor, trauma and iatrogenic
causes. Thus, we only included C5 palsy patients who had a degenerative pathology. C5 palsy was defined as deltoid muscle impairment of one or more grades in a manual muscle test (MMT) conducted within six weeks after surgery. The timing of C5 palsy onset was determined by medical chart review. When C5 palsy symptoms occurred on the day of surgery, they were marked as 0 days. The onset time of C5 palsy was determined as the post-operation day, when C5 palsy first occurred. Our research (human participants) was performed in accordance with relevant guidelines (Declaration of Helsinki) and informed consent was obtained from all participants. This study was approved by the Ethics Committee of each KCCSG member institution and had Institutional Review Board approval (The Catholic University of Korea, Hallym University, Gyeongsang National University School of Medicine, Seoul National University, Yonsei University College of Medicine, Sungkyunkwan University School of Medicine, The Leon Wiltse Memorial Hospital, Kyungpook National University Hospital, Inje University Seoul Paik Hospital, Pusan National University Hospital).

Radiographic Data Analysis

Radiological assessments were conducted using plain radiographs, magnetic resonance images (MRIs), and computed tomography (CT) images taken pre- and post-operatively. All radiographic measurements were using two PACS software programs (Petavision; Petavision Technologies, Inc., Seoul, Korea and M-view; M-view Technologies, Inc., Seoul, Korea).

Clinical Data and Radiological Factors Analysis

We reviewed medical chart records and investigated precise clinical features for each individual patient. The pre-operative clinical factors were demographic characteristics, body mass index (BMI), diabetes mellitus (DM), pre-operative symptoms (radiculopathy vs. myelopathy), symptom duration, and neurological function (Japanese Orthopedic Association; JOA score). We also investigated post-operative clinical factors: side of the palsy, weakness grade, onset and recovery levels of C5 palsy.

The following radiographic parameters were measured: (1) Cervical lordosis (C2–7 angle using Cobb’s method and Ishihara’s cervical curvature index) and T1-slope using plain radiographs taken pre- and post-operatively (Figure 1 A).10 (2) Transverse foraminal diameter of C4–5 (C4–5 FD) at the narrowest point using pre-operative MRI (Figure 1B); (3) Pre-operative high signal-intensity zone on T2-weighted MRIs (T2HIZ); (4) Cord rotation: the relative angle between the vertebral artery axis (the line between the centers of both vertebral arteries) and the spinal cord transverse axis (the line between right and left lateral margins of the spinal cord (Figure 1C); (4) Maximal occupying ratio: the maximal thickness of the compressive region divided by the anteroposterior diameter of the bony spinal canal using pre-operative MRI (Figure 1D).

To evaluate the relationship between C4–5 FD and the clinical appearance of C5 palsy, we sub-divided all patients (excluding those with bilateral C5 palsy) into four groups according to the absolute and relative foraminal diameters. In the first group (group A), the C4–5 FD value on the C5 palsy side was smaller than on the non-palsy side, and the absolute value of C4–5 FD was less than 2mm. In the second group (group B), the C4–5 FD value on the C5 palsy side was smaller than on the non-palsy side, but the absolute value of C4–5 FD was larger than 2mm. In the third group (group C), the C4–5 FD value on the C5 palsy side was...
larger than on the non-palsy side, but the absolute value of C4–5 FD was less than 2mm. In the fourth group (group D), the C4–5 FD value on the C5 palsy side was larger than on the non-palsy side, and the absolute value of C4–5 FD was larger than 2mm.

In order to identify the factors influencing the clinical course of C5 palsy, many simple comparison were performed according to the following various factors: (1) age; (2) sex; (3) BMI; (4) DM; (5) surgical approach; (6) main symptoms; (7) posterior operation (decompression vs. fusion); (8) palsy laterality (unilateral vs. bilateral); (9) Pre-operative diagnosis (HNP/ Spondylosis vs. OPLL); (10) onset of C5 palsy [early (0,1 days post-operative) vs. delayed (2 days post-operative)]; (11) T2HIZ grade (grade 0 vs. grade 1 vs. grade 2): groupings were classified by T2HIZ visibility (grade 0: definitely invisible, G1: ambiguous, and G2: definitely visible); (12) C5 palsy severity [severe (G1–2) vs. mild & moderate(G3–4)]; (13) Occupying ratio (greater or less than 50%).

**Statistical Analysis**

Data were analyzed using SAS version 9.3 (SAS Institute INC., Cary, NC). Chi-square test, Fisher's exact test, Bonferroni post hoc analysis, Wilcoxon rank-sum test (Mann-Whitney U test), t-test, and Kruskal Wallis tests were used for this study. To identify the most significant risk factors for severity of C5 palsy and onset of C5 palsy, risk factor analysis was performed by multivariate logistic regression analysis. Then odds ratios and their approximate 95% confidence intervals were calculated. Differences were considered significant at P < 0.05.

**Results**

Forty-six (54%) of the 85 patients had a positive T2HIZ. The mean value of C4-5 FD was 2.1 mm (right) and 2.0 mm (left). Cervical lordosis increased slightly (Δ 2.5°, P>0.05) and T1-slope decreased slightly (Δ 4.0°, P>0.05) after surgery. The occupying ratio was 53.0%, and the mean value of cord rotation was 4.6°. The mean duration of pre-operative symptoms was 13.2 months, and 45 patients (53%) showed radiculopathy as the main symptom. In this study, the pre-operative JOA score was 12.1, and the post-operative JOA score was 13.8. The mean MMT score was 2.7, and the mean value of recovery after 4.4 months was 4.0. The average onset of C5 palsy was 1.7 days after surgery (range, 0–19 days) (Table 1). Of the 20 open-door laminoplasty patients, only 3 cases experienced C5 palsy on the hinge side, and 17 cases experienced it on the open side (Table 1).

The proportion of group A was statistically higher in the severe (62.5%) and moderate (57.1%) paralysis groups than the other three groups (B, C, and D) (P<0.05). However, in the fair (G4) group, the proportion of group A was only 38.1% (8/21), which did not differ statistically from the other three groups (B,C,D) (Figure 2).

The following nine factors (sex, DM, BMI, surgical approach, main symptom, laterality, posterior fusion, diagnosis and occupying ratio) did not influence the clinical course of C5 palsy (onset, severity and recovery). Only the remaining four factors (age, the onset of C5 palsy, T2HIZ grade, C5 palsy severity) influenced the clinical course of C5 palsy (onset, severity, and recovery) (Table 2). The C5 palsy grade was worse in the
elderly group (2.5 vs. 3.0). The delayed onset group had shorter symptom duration and much worse C5 palsy grade than the early-onset group. Comparing the two different T2HIZ grade groups, the severity of the C5 palsy grade increased as the T2HIZ distribution became clearer (P< 0.05). The mild C5 palsy group showed earlier C5 palsy onset time than the severe group; and, the degree of cord rotation was higher in the mild group.

Influencing factors for onset of C5 palsy and severity of C5 palsy

Table 3 shows the results of univariate and multivariate logistic regression analysis for evaluating the influencing clinical and radiological factors for early-onset and severe state of C5 palsy. Multivariate logistic regression analysis showed that old age (OR 12.7 [95% CI 1.11-147.37], P=0.04), posterior approach (OR 39.1 [95% CI 2.24-682.31], P=0.04), radiculopathy (OR 13.5 [95% CI 1.06-171.2], P=0.04), OPLL (OR 13.7 [95% CI 1.33-140.77], P=0.02), small number of C2-7 angle (OR 0.83 [95% CI 0.71-0.98], P=0.02) and large number of C2-7 angle (OR 1.26 [95% CI 1.03-1.53], P=0.01) were the predictor for early onset of C5 palsy. Univariate logistic regression analysis showed that high-grade T2HIZ (p<0.05), a small size of C4-5 foramen diameter (p<0.05), and small cord rotation (p<0.05) were significantly associated with the severity of C5 palsy. In multivariate analysis, only two factors (C4-5 FD and cord rotation) were closely related to the severity of C5 palsy. Small dimension of C4-5 foramen (OR 0.58 [95% CI 0.37-0.92], P=0.04) and a small cord rotation (pre-operative) (OR 0.83 [95% CI 0.72-0.96], P=0.007), were the predictor for severe grade of C5 palsy (MMT; less than 2).

Discussion

Posterior reconstructive or fixation surgery has been reported to have a higher incidence of C5 palsy than conventional decompression surgery, and an excessive kyphosis correction is closely related to a high rate of C5 palsy (tethered effect).8,11-14 On the other hand, some authors have insisted that C5 palsy is a disorder of the intrinsic spinal cord, not the root lesion.15,16 Moreover, some other hypotheses have been presented for C5 palsy development, including that it is a central cord disorder (cord ischemia and reperfusion injury) or some other peripheral root disorder (iatrogenic thermal injury), but a definitive consensus has yet to be reached, and the precise mechanism remains unknown.16,17

The demographics of our population might provide considerable information about the clinical and radiological features of C5 palsy patients. First, C5 palsy occurs within two days after surgery with a weakness grade of 2.7, and about four months later, the paralysis has recovered to around a grade 4. Second, our results show that the occupying ratio was high in C5 palsy patients, which is similar to the previously published reports. Third, the lamina open side was more closely related to C5 palsy than the hinge side during open-door laminoplasty in this study.8,18 Generally, it was previously reported that the range of bilateral C5 palsy occurrence was very wide (up to 42%). However present study's result (12/85, 14%) was similar or slightly higher than that in a previous meta-analysis report (8%).2,18

In recent studies, the C4–5 foramen stenosis has been considered the most relevant risk factor for C5 palsy during cervical operations.3,8,11,17,19-22 Previous clinical data suggested a reference point for stenosis (C5
palsy group: 1.99–2.70mm, non-C5 palsy group: 2.76–3.20mm) that can cause C5 palsy. Lee at al. insisted that severe stenosis of the C4–5 FD (less than 2mm) can induce C5 palsy at a rate of about 16 times higher than seen with non-severe C4–5 stenosis.19 Our results showed that patients with severe paralysis (MMT ≤3) were more likely to belong to group A, which suggested a close correlation between the degree of paralysis and the degree of C4-5 foraminal stenosis. In other words, those with a severe state of C5 palsy had smaller absolute dimensions for C4–5 FD and a smaller C4–5 FD on the affected side than the non-affected side. The above results could be confirmed once again through univariate and multivariate analysis.

Generally, the larger the cord rotation, the higher the probability of C5 palsy.23-25 However, there was no content on the clinical course of C5 palsy by cord rotation in the previous studies. Unexpectedly, the present study revealed that the degree of C5 palsy is more serious, when there is little cord rotation in pre-operative. Among the pathophysiology of C5 palsy, the tethered effect may be most commonly accepted theory. Uneven and asymmetric cord shift by cord rotation may be reasonable theoretical grounds for explaining the relationship between the C5 palsy side and lamina hinge side in laminoplasty. Considering the above results, it can be inferred that the C5 palsy, which was not mainly caused by cord rotation (tethered effect), could be more serious.

T2HIZ was reported to be associated with C5 palsy occurrence and prognosis in some papers.7,26 We did not find T2HIZ relevance to the degree of C5 palsy when we simply evaluated its presence or absence. However, according to clarity, when we subdivided it into three groups, we found that the degree of clarity may be related to the severity of C5 palsy symptoms.8 On univariate analysis, the severity of C5 palsy was closely related to T2HIZ grade. However, there was no statistical significance in multivariate analysis in the present study.

In terms of the onset of C5 palsy, differences were closely related to the primary pathology type in the present study. The OPLL group had a high probability of belonging to the early onset group, and the delayed onset group had a statistically high HNP/spondylosis patient composition ratio (Table 4). The above result was re-confirmed through multivariate analysis. OPLL pathology (OR 13.7 [95% CI 1.33-140.77], P=0.02) was closely related to the early-onset of C5 palsy in the present study. Previously, Takenaka et al. showed that the prevalence rates of C5 palsy (OPLL) were higher in both early and late-onset in their meta-analysis.27 However, our multi-centered cohort study revealed that OPLL pathology was more closely related to the early onset of C5 palsy.

The following five factors also were identified as a potential factor that can predict early onset of C5 palsy: (1) old age, (2) radiculopathy, (3) posterior approach (4) pre-operative C2-7 angle and (5) post-operative C2-7 angle. Generally, reperfusion injury (myelopathy) can explain the pathophysiology of the late onset of C5 palsy and lag correction effect (hypercorrection) may explain the phenomenon of early onset of C5 palsy.12,28 From this point of view, depending on the main symptom and the difference of C2-7 angle could sufficiently explain the above results. A recent meta-analysis also showed that the posterior approach was closely associated with the early onset of C5 palsy. The above previous results are consistent with our present finding.27
Limitation and Interpretation

First, this study was a retrospective design. Second, this study lacks an analysis of a matched control cohort without post-operative C5 palsy. Therefore, a matched-control study could proceed in the future. Third, it may be worth recalling that the definition of C5 paralysis can significantly impact study results, as the absolute definition of C5 palsy has not been established. Fourth, there can be measurement error in various aspects from the incorrect measurement method (ex. C4-5 foramen diameter in axial view vs oblique sagittal view).

Conclusion

We found a close correlation between the degree of paralysis and C4–5 FD. And, the less degree the cord rotation, the more severe the symptoms of C5 palsy. Besides, the degree of T2HIZ clarity can be related to the severity of C5 palsy motor grade. Age, primary pathology, surgical approach, main symptom and C2-7 angle (pre and postoperative) are important factors determining the onset of C5 palsy.

Declarations

Competing interest

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

Author Contributions

Study design and drafted the article: Ho Jin Lee/ Jae Keun Oh/ Jae Taek Hong, Collected data and supervised the project: Dong Ho Kang, MD / Ki-Jeong Kim / Chun Kee Chung / Jung-Woo Hur / Seong Yi / Jun Jae Shin / Sun Ho Lee / Kyung Chul Choi / Kyung Hyun Kim / Dae-Chul Cho / Yong Jun Jin / In Ho Han, Data Analysis Ho Jin Lee / Jae Taek Hong

References

1. Wang, T., Wang, H., Liu, S. & Ding, W. Y. Incidence of C5 nerve root palsy after cervical surgery: A meta-analysis for last decade. Medicine 96, e8560, doi:10.1097/md.0000000000008560 (2017).
2. Sakaura, H., Hosono, N., Mukai, Y., Ishii, T. & Yoshikawa, H. C5 palsy after decompression surgery for cervical myelopathy: review of the literature. Spine 28, 2447-2451, doi:10.1097/01.brs.0000090833.96168.3f (2003).
3. Gu, Y. et al. Incidence and risk factors of C5 palsy following posterior cervical decompression: a systematic review. PloS one 9, e101933, doi:10.1371/journal.pone.0101933 (2014).
4. Zhao, X. et al. Extensive laminectomy for the treatment of ossification of the posterior longitudinal ligament in the cervical spine. Archives of orthopaedic and trauma surgery 132, 203-209, doi:10.1007/s00402-011-1420-4 (2012).
5. Komagata, M. et al. Prophylaxis of C5 palsy after cervical expansive laminoplasty by bilateral partial foraminotomy. The spine journal : official journal of the North American Spine Society 4, 650-655,
6. Bydon, M. et al. Incidence and prognostic factors of c5 palsy: a clinical study of 1001 cases and review of the literature. *Neurosurgery* **74**, 595-604; discussion 604-595, doi:10.1227/01.NEU.0000000000000322 (2014).

7. Liu, G., Reyes, M. R. & Riew, K. D. Why Does C5 Palsy Occur After Prophylactic Bilateral C4-5 Foraminotomy in Open-Door Cervical Laminoplasty? A Risk Factor Analysis. *Global spine journal* **7**, 696-702, doi:10.1177/2192568217699191 (2017).

8. Katsumi, K., Yamazaki, A., Watanabe, K., Ohashi, M. & Shoji, H. Analysis of C5 palsy after cervical open-door laminoplasty: relationship between C5 palsy and foraminal stenosis. *Journal of spinal disorders & techniques* **26**, 177-182, doi:10.1097/bsd.0b013e31823db346 (2013).

9. Oh, J. K. et al. Epidemiology of C5 Palsy after Cervical Spine Surgery: A 21-Center Study. *Neurospine* **16**, 558-562, doi:10.14245/ns.1938142.071 (2019).

10. Takeshita, K., Murakami, M., Kobayashi, A. & Nakamura, C. Relationship between cervical curvature index (Ishihara) and cervical spine angle (C2–7). *Journal of orthopaedic science : official journal of the Japanese Orthopaedic Association* **6**, 223-226, doi:10.1007/s0077610060223 (2001).

11. Kurakawa, T., Miyamoto, H., Kaneyama, S., Sumi, M. & Uno, K. C5 nerve palsy after posterior reconstruction surgery: predictive risk factors of the incidence and critical range of correction for kyphosis. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society* **25**, 2060-2067, doi:10.1007/s00586-016-4548-7 (2016).

12. Hojo, Y. et al. A late neurological complication following posterior correction surgery of severe cervical kyphosis. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society* **20**, 890-898, doi:10.1007/s00586-010-1590-8 (2011).

13. Nakashima, H. et al. Multivariate analysis of C-5 palsy incidence after cervical posterior fusion with instrumentation. *Journal of neurosurgery. Spine* **17**, 103-110, doi:10.3171/2012.4.spine11255 (2012).

14. Takemitsu, M., Cheung, K. M., Wong, Y. W., Cheung, W. Y. & Luk, K. D. C5 nerve root palsy after cervical laminoplasty and posterior fusion with instrumentation. *Journal of spinal disorders & techniques* **21**, 267-272, doi:10.1097/bsd.0b013e31812f6f54 (2008).

15. Hasegawa, K., Homma, T. & Chiba, Y. Upper extremity palsy following cervical decompression surgery results from a transient spinal cord lesion. *Spine* **32**, E197-202, doi:10.1097/01.brs.0000257576.84646.49 (2007).

16. Yoshihara, H., Margalit, A. & Yoneoka, D. Incidence of C5 Palsy: Meta-Analysis and Potential Etiology. *World neurosurgery*, doi:10.1016/j.wneu.2018.10.159 (2018).

17. Imagama, S. et al. C5 palsy after cervical laminoplasty: a multicentre study. *The Journal of bone and joint surgery. British volume* **92**, 393-400, doi:10.1302/0301-620x.92b3.22786 (2010).

18. Chen, G., Wang, Y., Wang, Z., Zhu, R. & Yang, H. Analysis of C5 palsy in cervical myelopathy with massive anterior compression following laminoplasty. **13**, 26, doi:10.1186/s13018-018-0715-3 (2018).
19. Lee, H. J., Ahn, J. S., Shin, B. & Lee, H. C4/5 foraminal stenosis predicts C5 palsy after expansive open-door laminoplasty. *European spine journal: official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society* **26**, 2340-2347, doi:10.1007/s00586-017-5077-8 (2017).

20. Kang, K. C. *et al.* Preoperative Risk Factors of C5 Nerve Root Palsy After Laminectomy and Fusion in Patients With Cervical Myelopathy: Analysis of 70 Consecutive Patients. *Clinical spine surgery* **30**, 419-424, doi:10.1097/bsd.0000000000000505 (2017).

21. Nori, S. *et al.* Cervical laminectomy of limited width prevents postoperative C5 palsy: a multivariate analysis of 263 muscle-preserving posterior decompression cases. *European spine journal: official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society* **26**, 2393-2403, doi:10.1007/s00586-017-5202-8 (2017).

22. Odate, S., Shikata, J., Yamamura, S. & Soeda, T. Extremely wide and asymmetric anterior decompression causes postoperative C5 palsy: an analysis of 32 patients with postoperative C5 palsy after anterior cervical decompression and fusion. *Spine* **38**, 2184-2189, doi:10.1097/brs.0000000000000019 (2013).

23. Eskander, M. S. *et al.* The association between preoperative spinal cord rotation and postoperative C5 nerve palsy. *The Journal of bone and joint surgery. American volume* **94**, 1605-1609, doi:10.2106/jbjs.k.00664 (2012).

24. Chugh, A. J. S., Weinberg, D. S., Alonso, F. & Eubanks, J. D. Comparing the Effectiveness of Sagittal Balance, Foraminal Stenosis, and Preoperative Cord Rotation in Predicting Postoperative C5 Palsy. *Clinical spine surgery* **30**, E1256-e1261, doi:10.1097/bsd.0000000000000462 (2017).

25. Chugh, A. J., Gebhart, J. J. & Eubanks, J. D. Predicting Postoperative C5 Palsy Using Preoperative Spinal Cord Rotation. *Orthopedics* **38**, e830-835, doi:10.3928/01477447-20150902-63 (2015).

26. Ikegami, S. *et al.* Preoperative spinal cord damage affects the characteristics and prognosis of segmental motor paralysis after cervical decompression surgery. *Spine* **39**, 463-468, doi:10.1097/brs.000000000000175 (2014).

27. Takenaka, S., Nagamoto, Y., Aono, H., Kaito, T. & Hosono, N. Differences in the time of onset of postoperative upper limb palsy among surgical procedures: a meta-analysis. *The spine journal: official journal of the North American Spine Society* **16**, 1486-1499, doi:10.1016/j.spinee.2016.09.014 (2016).

28. Wakasa, S., Shiiya, N., Tachibana, T., Ooka, T. & Matsui, Y. A semiquantitative analysis of reactive astrogliosis demonstrates its correlation with the number of intact motor neurons after transient spinal cord ischemia. *The Journal of thoracic and cardiovascular surgery* **137**, 983-990, doi:10.1016/j.jtcvs.2008.10.002 (2009).

**Tables**

**Table 1** Demographics of C5 palsy patient and their clinical and radiological findings.

**Table 2**. Comparison according to various clinical and radiological factors.
| Factors                                                                 | Mean ± SD                                      |
|------------------------------------------------------------------------|-----------------------------------------------|
| Age (years)                                                            | 61.1 ± 11.9                                   |
| Sex (n)                                                                | Female (19) / Male (66)                        |
| Operation time (minute, mean ± SD) (whole patients/ anterior approach/ posterior approach) | 169 ± 90 / 185 ± 121 / 160 ± 66               |
| Blood loss (cc, mean ± SD) (whole patients/ anterior approach/ posterior approach) | 309 ± 237 / 272 ± 257 / 326 ± 224              |
| BMI (body mass index)                                                  | 24.3 ± 2.9                                    |
| DM (n)                                                                 | 25 (positive) / 60 (negative)                 |
| Existence of T2HIZ (n)                                                 | 46 (positive) / 39 (negative)                 |
| Bilateral C5 palsy vs Unilateral C5 palsy (n)                          | 12 vs 73                                       |
| Palsy side after open-door laminoplasty (n)                            | Open side 17 / Hinge side 3                   |
| Surgical approach (anterior/ posterior/ anterior and posterior) (n)     | 25 / 57 / 3                                    |
| C4-5 foraminal diameter (mm), right                                    | 2.1 ± 1.2                                     |
| C4-5 foraminal diameter (mm), left                                     | 2.0 ± 1.3                                     |
| C4-5 foraminal diameter (right, left) in Group A,B,C and D (mm)        | A(1.6 / 1.5), B(3.3/3.1), C(0.8/1.3), D(2.5/2.4) |
| C2-7 angle (pre-OP) (˚)                                                | 8.5 ± 12.8                                    |
| C2-7 angle (post-OP)( ˚)                                               | 11.0 ± 11.3                                   |
| T1-slope (pre-OP) (˚)                                                  | 22.6 ± 10.5                                   |
| T1-slope (post-OP) (˚)                                                 | 18.6 ± 19.1                                   |
| Ishihara index (pre-OP)                                                | 0.1 ± 0.1                                     |
| Ishihara index (post-OP)                                               | 0.1 ± 0.1                                     |
| Occupying ratio (%)                                                    | 53.0 ± 10.0                                   |
| Cord rotation (˚)                                                      | 4.6 ± 4.3                                     |
| Symptom duration (months)                                              | 13.2 ± 19.1                                   |
| Main symptoms (radiculopathy vs myelopathy) (n)                        | Radiculopathy (45) / Myelopathy (40)          |
| JOA score (pre-operation)                                              | 12.1 ± 3.0                                    |
| JOA score (post-operation)                                             | 13.8 ± 2.1                                    |
| Onset of C5 palsy                                                      | 1.7 ± 2.8                                     |
| MMT grade of C5 palsy                                                  | 2.7 ± 2.0                                     |
|                          |         |
|--------------------------|---------|
| MMT grade after C5 palsy recovery | 4.0 ± 1.0 |
| Recovery period (months)  | 4.4 ± 4.2 |
| Comparison factors | Age | Onset of C5 palsy | T2HIZ grade | C5 palsy grade |
|--------------------|-----|------------------|-------------|---------------|
|                    | <60 yrs (n=41) | ≥ 60 yrs (n=44) | Early (< 2 day) (n=50) | Delayed (≥ 2 days) (n=35) |
| T2HIZ (positive/total) | 19 / 41 (0.11) | 28 / 44 | 24 / 50 (0.09) | 23 / 35 |
|                      |                  |                  |                  |              |
| C4-5 FD (mm), right | 2.1 (0.91) | 2.1 (0.84) | 2.1 (0.21) | 1.7 (0.05) |
| C4-5 FD (mm), left  | 2.1 (0.27) | 1.8 (0.17) | 2.0 (0.05) | 1.5 (0.05) |
| C2-7 angle (pre-OP) | 5.1 (<0.05) | 11.4 (0.24) | 6.9 (0.29) | 7.2 (0.98) |
| C2-7 angle (post-OP) | 7.3 (<0.05) | 13.9 (0.47) | 10.1 (0.41) | 11.4 (0.98) |
| T1-slope (pre-OP) | 22.8 (0.50) | 22.5 (0.57) | 22.9 (0.89) | 24.5 (0.84) |
| T1-slope (post-OP) | 19.1 (0.84) | 18.0 (0.41) | 20.9 (0.76) | 15.7 (0.37) |
| Ishihara index (pre-OP) | 0.08 (<0.01) | 0.15 (0.94) | 0.12 (0.08) | 0.13 (0.74) |
| Ishihara index (post-OP) | 0.07 (<0.05) | 0.13 (0.57) | 0.10 (0.40) | 0.10 (0.81) |
| Occupying ratio % | 53.0 (0.50) | 53.3 (0.99) | 53.0 (0.39) | 50.6 (0.13) |
|                      | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | Value 6 | Value 7 |
|----------------------|---------|---------|---------|---------|---------|---------|---------|
| **Cord rotation**    | 4.2     | 5.2     | 4.9     | 4.4     | 5.2     | 4.7     | 2.5     | 5.5     |
| **Symptom duration** | 12.3    | 14.2    | 16.8    | 8.7     | 13.6    | 16.1    | 12.2    | 14.2    |
| **JOA score (pre-OP)** | 12.9 | 11.2 | 11.6 | 12.7 | 12.3 | 12.0 | 12.7 | 11.8 |
| **JOA score (post-OP)** | 14.5 | 13.0 | 13.4 | 14.2 | 14.0 | 13.7 | 13.9 | 14.0 |
| **Onset of C5 palsy** | 1.8 | 1.7 | 0.2 | 3.9 | 1.1 | 2.0 | 2.8 | 1.3 |
| **C5 palsy grade**   | 3.0 | 2.5 | 3.0 | 2.5 | 3.1 | 2.5 | 1.7 | 3.4 |
| **C5 palsy recovery** | 4.2 | 3.9 | 4.2 | 3.7 | 4.2 | 4.0 | 3.4 | 4.3 |

**Table 3.** Multivariate analysis for factors related to early onset C5 palsy and severe status of C5 palsy.
|                           | **Univariate (Early onset of C5 palsy)** | **Multivariate (Early onset of C5 palsy)** | **Univariate (Severe status of C5 palsy)** | **Multivariate (Severe status of C5 palsy)** |
|---------------------------|-----------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|
|                           | OR (95% CI)                              | P-value                                  | OR (95% CI)                              | P-value                                  |
| **Age**                   | 0.75 (0.31-1.78)                         | 0.51                                      | 12.7 (1.11-147.37)                       | <0.05†                                    |
|                           |                                         |                                           | 1.60 (0.63-4.01)                         | 0.31                                      |
| **Sex**                   | 1.26 (0.44-3.61)                         | 0.66                                      | 0.87 (0.08-9.33)                         | 0.91                                      |
|                           |                                         |                                           | 0.66 (0.21-2.08)                         | 0.48                                      |
|                           |                                         |                                           | 2.89 (0.11-73.82)                        | 0.52                                      |
| **BMI (body mass index)** | 1.12 (0.95-1.31)                         | 0.15                                      | 0.93 (0.67-1.29)                         | 0.69                                      |
|                           |                                         |                                           | 0.95 (0.81-1.12)                         | 0.57                                      |
|                           |                                         |                                           | 0.85 (0.57-1.26)                         | 0.42                                      |
| **DM**                    | 0.53 (0.19-1.47)                         | 0.22                                      | 7.70 (0.69-85.91)                        | 0.09                                      |
|                           |                                         |                                           | 0.68 (0.25-1.86)                         | 0.46                                      |
|                           |                                         |                                           | 2.54 (0.17-37.16)                        | 0.49                                      |
| **Surgical approach (posterior)** | 1.21 (0.46-3.15) | 0.69                                      | 39.16 (2.24-682.31)                       | <0.05†                                    |
|                           |                                         |                                           | 0.64 (0.06-6.67)                         | 0.71                                      |
| **Main symptom (radiculopathy)** | 0.44 (0.18-1.07) | 0.07                                      | 13.5 (1.06-171.2)                        | <0.05†                                    |
|                           |                                         |                                           | 0.72 (0.29-1.80)                         | 0.48                                      |
|                           |                                         |                                           | 16.9 (0.82-348.67)                       | 0.06                                      |
| **Diagnosis (OPLL)**      | 1.96 (0.78-4.93)                         | 0.15                                      | 13.7 (1.33-140.77)                       | <0.05†                                    |
|                           |                                         |                                           | 0.39 (0.1-1.33)                          | 0.13                                      |
|                           |                                         |                                           | 5.13 (0.40-65.78)                        | 0.20                                      |
| **T2HIZ (presence)**      | 1.84 (0.75-4.50)                         | 0.18                                      |                                         |                                           |
|                           |                                         |                                           | 0.40 (0.15-1.05)                         | 0.06                                      |
|                           |                                         |                                           | 5.26 (0.45-61.28)                        | 0.18                                      |
| **T2HIZ (grade2 vs Grade 0)** | 0.52 (0.19-1.38) | 0.19                                      | 0.17 (0.02-1.22)                         | 0.07                                      |
|                           |                                         |                                           | 3.30 (1.18-9.24)                         | <0.05†                                    |
| **C4-5 FD (affected side)** | 1.11 (0.76-1.62) | 0.58                                      | 0.56 (0.22-1.39)                         | 0.21                                      |
|                           |                                         |                                           | 0.58 (0.37-0.92)                         | <0.05†                                    |
| **C2-7 angle(Pre-OP)**    | 0.97 (0.93-1.01)                         | 0.15                                      | 0.83 (0.71-0.98)                         | <0.05†                                    |
|                           |                                         |                                           | 1.02 (0.98-1.06)                         | 0.29                                      |
|                           |                                         |                                           | 0.99 (0.83-1.18)                         | 0.93                                      |
| **C2-7 angle(Post-OP)**   | 0.98 (0.94-1.02)                         | 0.51                                      | 1.26 (1.03-1.53)                         | <0.05†                                    |
|                           |                                         |                                           | 1.01 (0.96-1.05)                         | 0.73                                      |
| **C2-7 SVA (Pre-OP)**     | 1.01 (0.96-1.03)                         | 0.89                                      | 1.01 (0.93-1.10)                         | 0.72                                      |
|                           |                                         |                                           | 0.98 (0.94-1.01)                         | 0.31                                      |
|                           |                                         |                                           | 0.99 (0.89-1.11)                         | 0.96                                      |
|                  | Early onset (n=50) | Delayed onset (n=35) | P-value (Early vs Delayed) |
|------------------|--------------------|----------------------|----------------------------|
| C2-7 SVA (Post-OP) | 0.97 (0.94-1.01) | 0.99 (0.96-1.03) | 0.97 (0.94-1.13) | 0.49 |
| T1-slope (Pre-OP)  | 1.01 (0.95-1.06) | 0.98 (0.92-1.05) | 0.71 |
| T1-slope (Post-OP) | 0.98 (0.95-1.01) | 1.01 (0.97-1.04) | 0.56 |
| Occupying ratio   | 1.33 (0.52-3.38) | 0.54 (0.22-1.52) | 0.27 (0.47-299.17) | 0.13 |
| Cord rotation     | 1.03 (0.92-1.14) | 1.23 (0.97-1.56) | 0.07 (0.72-0.96) | <0.05† |
| Symptom duration  | 1.02 (0.99-1.06) | 1.03 (0.98-1.09) | 0.18 (0.96-1.01) | 0.51 (0.93-1.03) | 0.54 |
| JOA score (Pre-OP)| 0.88 (0.73-1.05) | 0.18 | 1.12 (0.93-1.35) | 0.20 |
| JOA score (Post-OP)| 0.84 (0.63-1.11) | 0.22 | 0.84 (0.63-1.13) | 0.26 |

Table 4. Distribution of patients according to main pathology and C5 palsy onset time.

|                  | Early onset (n=50) | Delayed onset (n=35) | P-value (Early vs Delayed) |
|------------------|--------------------|----------------------|----------------------------|
| OPLL (n=30)      | 22                 | 8                    | < 0.01                     |
| HNP / Spondylosis (n=55) | 28 | 27 | > 0.05 |

P-value (OPLL vs HNP/spondylosis)
Figure 1

Measurement and analysis of radiographic data. A; C2-7 angle and Ishihara’s curvature index, B; transforaminal diameter of C4-5, C; occupying ratio, D; cord rotation.
Figure 2

Patients with different C4-5 foraminal diameters (absolute or relative) are distributed according to the degree of C5 palsy (severe, moderate and fair). The proportion of group A was statistically higher in the severe and moderate paralysis groups than the other three groups (B, C, and D).