

ARTICLE



Nerve root morphological and functional changes after degenerative cervical myelopathy surgery: preliminary study using ultrasound and electrophysiology

Nobuaki Tadokoro¹, Kyuichi Hashimoto¹, Yuki Yanagawa¹, Haruka Maehara¹ and Toshihiro Sano¹✉

© The Author(s), under exclusive licence to International Spinal Cord Society 2021

STUDY DESIGN: A prospective observational study.

OBJECTIVES: To depict morphological and functional changes in the cervical nerve roots before and after spinal cord decompression surgery for degenerative cervical myelopathy (DCM).

SETTING: A general hospital in Japan.

METHODS: Thirteen DCM patients who underwent posterior spinal cord decompression surgery, laminoplasty or laminectomy, were included in this study. The neural foramen shown on MRI and the cross-sectional area (CSA) of the nerve roots on ultrasound were used to evaluate the C5 and C6 nerve roots. The compound muscle action potentials (CMAPs) of deltoid and biceps muscle were also recorded.

RESULTS: All patients showed sensorimotor functional improvement without the postoperative C5 palsy after surgery. Foraminal stenosis and preoperative CSA of the nerve root: C4/5 foramen and C5 nerve root, C5/6 foramen and C6 nerve root, had no significant correlation ($P = 0.53$ and 0.08). CSA of the C5 nerve root displayed no significant change before and after surgery ($P = 0.2$), however, that of the C6 nerve root reduced significantly after surgery ($P = 0.038$). The amplitude of the deltoid and biceps CMAPs displayed no significant change before and after surgery ($P = 0.05$ and 0.05).

CONCLUSION: The C6 nerve root CSA change was observed after spinal cord decompression surgery with functional recovery. However, deltoid and biceps CMAPs amplitude showed no significant change. Independent CSA changes on ultrasound might be useful when conducting a functional evaluation of the postoperative nerve root.

SPONSORSHIP: The Grant of Japan Orthopaedics and Traumatology Research Foundation No. 395.

Spinal Cord (2022) 60:301–305; <https://doi.org/10.1038/s41393-021-00707-4>

BACKGROUND

Degenerative cervical disease manifested as myelopathy and/or radiculopathy is a common pathological condition affecting the adult population [1]. As the spinal cord and nerve roots are located close to one other, the compressive lesions of these structures can develop concurrently. Spinal cord pathology such as cord compression and intramedullary damage is well elucidated by MRI, which plays a crucial role in degenerative cervical myelopathy (DCM) management. Cervical foraminal stenosis causing nerve root compression is also depicted by MRI. However, there are still limitations to how much they can help distinguish compressed cervical nerve root in relation to its clinical symptoms [2]. MRI findings of cervical foraminal stenosis mainly focused on structural abnormalities resulting in cervical nerve root compression: cervical disc pathology, facet joint hypertrophy and yellow ligament hypertrophy [2, 3]. Recently, nerve ultrasound (US) is becoming the established measure to directly observe cervical nerve roots and the pathological conditions [4]. Furthermore, preoperative C5 nerve root swelling has been reported in some DCM patients [5]. However, it is uncertain whether spinal cord

decompression affects cervical nerve roots or not. The aim of this study was to demonstrate morphological changes in the cervical nerve roots before and after spinal cord decompression surgery in association with the amplitude of compound muscle action potentials, which represent motor function.

MATERIALS & METHODS

From April 2019 to Dec 2020, a total of thirty-two consecutive degenerative cervical myelopathy patients underwent surgical treatment. The varieties of surgical procedures, such as anterior decompression with fusion, posterior laminoplasty or laminectomy with or without foraminotomy, were performed to decompress the spinal cord and nerve root. In this study, to investigate how spinal cord decompression affects the nerve root, thirteen patients with cervical degenerative myelopathy were included based on the surgical procedure aimed to decompress only the spinal cord such as laminoplasty or laminectomy. Myelopathy resulted from cervical spondylosis in nine patients, cervical disc herniation in one, and ossification of posterior longitudinal

¹Department of Orthopaedic surgery, Kochi prefectural Hata Kenmin hospital, Sukumo, Kochi, Japan. ✉email: nobuaki.tadokoro@gmail.com

Received: 1 February 2021 Revised: 10 September 2021 Accepted: 13 September 2021

Published online: 23 September 2021

ligament (OPLL) in three. There were nine male and four female patients. The mean age of the subjects was 69 years old (58–79). The preoperative MRI demonstrated spinal cord compression and intramedullary change compatible with DCM diagnosis (Table 1). The Japanese Orthopaedic Association (JOA) score was used for the functional evaluation. The JOA score is a 17-point scale that indicates the severity of cervical myelopathy based on sensorimotor and bladder function [6]. Strength of the deltoid and biceps muscles was assessed by manual muscle testing using medical research council grade (0–5) [7].

All patients underwent the cervical nerve root ultrasound examination and compound muscle action potentials recorded at deltoid and biceps muscles before and two weeks after operation. The cervical nerve root ultrasound examination was performed using SONIMAGE HS1 (KONICA MINOLTA, Tokyo, Japan) with an 18-MHz linear-array transducer (L18-4). The participants were tested in the supine position. The absent C7 anterior tubercle and the large anterior tubercle of C6 are the key landmarks to confirm the cervical level. Other structures including thyroid, carotid artery and vein and scalene muscles also help us to locate cervical nerve roots. The diameter (D) and the transverse diameter (TD) of bilateral C5 and C6 nerve roots were measured at the point where the nerve emerges between the anterior and posterior tubercle of the transverse process. The cross-sectional area (CSA) was calculated using the following formula: $D \times TD \times \pi/4$. The measurements were made more than twice and the mean CSA value was used for analysis. The ultrasound examination was conducted by a single physician (N.T) with more than five years experience in nerve ultrasound. The intraobserver and test-retest reliabilities were evaluated before we started this study. The Intraclass correlation coefficient (ICC) estimates and their 95% confident intervals were calculated using SPSS statistical package version 23 (SPSS Inc., Chicago, IL) based on a mean-rating ($k = 2$), absolute-agreement, 2-way mixed-effects model [8]. The ICC was 0.95 (95% CI: 0.85–0.98). Values <0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability. The results of the ICC were evaluated as “good” to “excellent.”

The degree of foraminal stenosis on MRI was evaluated using the formula reported by Kim [9]: the narrowest width of neural foramen/extraforaminal nerve root on the axial T2-weighted images at the intervertebral disc level. The correlation between foraminal stenosis on MRI and CSA of nerve roots was examined.

The compound muscle action potentials (CMAPs) were recorded using the standard EMG machine (NeuroPak, Nihon Koden, Tokyo, Japan). The recording and reference electrodes were placed on the middle of the deltoid and biceps muscles and the acromion and lateral epicondyle, respectively. The Erb-point electrical stimulation, a square wave of 0.1 ms in duration, was given at 1/s. We measured the amplitudes of CMAPs from the baseline to the negative peak.

All participants provided informed consent. This study was approved by our hospital institutional review board. This study was supported by the Grant of Japan Orthopaedics and Traumatology Research Foundation No. 395.

Wilcoxon signed rank test and Spearman's correlation test were respectively used for the paired samples and the correlation. $P < 0.05$ was considered to be significant. All statistical analyses were performed with EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria) [10].

RESULTS

Table 2 showed JOA scores, Manual Muscle Testing of deltoid and biceps, the CSA of the C5 and C6 nerve roots and the CMAPs of deltoid and biceps. The JOA scores before and two weeks after surgery were 8.4 (3–13.5) (95% CI: 6.3–10.5) and 11 (6.5–15) (95% CI: 9.4–12.6), respectively. All patients displayed a postoperative functional improvement without a new onset of C5 palsy.

The mean degrees of the C4–5 and C5–6 foraminal stenosis on MRI were 67.6 (25.0–123.1) (95% CI: 58.5–76.7) % and 56.5 (21.7–82.4) (95% CI: 50.1–62.9) %, respectively. Each pair of foraminal stenosis and CSA of the nerve roots, that is, C4/5 foramen and C5 nerve root, C5/6 foramen and C6 nerve root, showed no significant correlation ($P = 0.53$ and 0.08).

The CSA of C5 nerve root displayed no significant change between before and after surgery ($P = 0.2$), however, that of the C6 nerve root reduced significantly ($P = 0.038$) after surgery.

The amplitude of the deltoid and biceps CMAPs showed no significant change before and after surgery ($P = 0.05$ and 0.05).

Case presentation

A sixty-seven-year-old male patient (patient no. 5) with gait disturbance was referred to our hospital. He was diagnosed with DCM by sensorimotor dysfunction with hyperreflexia and cord

Table 1. Patient demographics.

Patient	Age	Gender	Diagnosis	Level(s) of cord compression with intramedullary signal change	Surgical procedure
1	74	M	CSM	C4–5, 5–6	Laminoplasty
2	77	F	CDH	C4–5, 5–6	Laminoplasty
3	71	M	OPLL	C3–4, 4–5, 5–6, 6–7, 7–T1	Laminoplasty
4	62	F	CSM	C3–4	Laminectomy
5	67	M	CSM	C4–5, 5–6	Laminoplasty
6	66	M	OPLL	C3–4	Laminoplasty
7	58	M	CSM	C5–6, 6–7	Laminoplasty
8	71	F	CSM	C4–5, 5–6	Laminoplasty
9	69	F	OPLL	C3–4, 4–5	Laminoplasty
10	59	M	CSM	C6–7	Laminoplasty
11	79	M	CSM	C3–4, 4–5	Laminectomy
12	77	M	CSM	C6–7	Laminoplasty
13	73	M	CSM	C3–4, 4–5	Laminoplasty

CSM cervical spondylotic myelopathy, CDH cervical disc herniation, OPLL ossification of longitudinal ligament.

Table 2. JOA score, MMT, CSA and CMAPs before and after surgery.

Patient	JOA score, CSA and CMAPs before and after surgery R/L		MMT (0-5)		Biceps		C5 nerve root		C6 nerve root		Deltoid		Biceps	
	Pre-op	2 weeks post-op	Pre-op	2 weeks post-op	Pre-op	2 weeks post-op	Pre-op	2 weeks post-op	Pre-op	2 weeks post-op	Pre-op	2 weeks post-op	Pre-op	2 weeks post-op
1	3	6.5	R 5	5	5	5	5.8	2.7	12.2	4.8	10.4	10.5	6.8	3.1
2	12	15	L 5	5	4	5	8.8	2.2	12.9	2.3	5.4	5.7	2.1	1.9
3	6	9.5	R 5	5	5	5	5.2	4.6	7.9	7.5	9.4	7.8	8	6.2
4	4	8	L 5	5	5	5	8.3	6.5	12.1	8	7.8	7.3	7.8	5.1
5	8.5	11.5	R 5	5	5	5	2.9	2.7	4	3.8	3.1	2.6	3.4	7.1
6	13.5	14	L 5	5	5	5	2.9	2.9	9.9	5	9	8.7	8.2	9.6
7	12	13	R 2	3	3	4	16.2	7	11.2	5.5	3.3	3.4	3.3	2.3
8	9.5	11.5	L 2	3	3	4	7.8	4.3	6.2	2	4.9	4.1	5.4	2.6
9	11	14	R 5	5	4	5	10.9	15.4	24.6	18.2	9.2	6.2	3.7	2.6
10	11.5	14	L 5	5	4	5	9.6	13.9	12.8	17.4	6.3	5.8	4	3
11	6	9	R 5	5	5	5	11.4	8	15.1	12.3	7.8	8.9	6.2	4.9
12	8.5	10	L 5	5	5	5	12.3	8.2	9.5	12.2	7.1	9.9	7.3	4.8
13	4	9.5	R 4	4	4	5	5.7	8.3	18.1	10.4	4.6	5.9	2.4	2.4
			L 5	5	5	5	16.2	6.7	20.2	5.7	7.3	6.7	8.3	3.8
			R 4	4	4	4	6.1	5.8	5.1	10.8	5.4	3.5	7.7	3.1
			L 4	4	4	4	5.4	9.9	12.8	11	5.1	2	1.9	4.1
			R 5	5	5	5	3	9.5	5.6	11.5	6.1	4.7	6.6	5.8
			L 5	5	5	5	5.1	8.4	12	9.9	6.8	2.2	5.5	6.7
			R 5	5	5	5	6.2	10.1	6.4	7.8	10.6	11	7.4	5.4
			L 5	5	5	5	7.9	8.2	9	9.5	12.6	10.5	11.5	7.3
			R 2	2	2	3	6	4	12.7	7.4	1.1	0.9	1.7	1.9
			L 5	5	5	5	9	3.4	16.9	11.7	5.6	4.9	2.7	4.6
			R 5	5	5	5	8.1	7.9	8.9	12.8	5.3	6.1	7.7	6.1
			L 5	5	5	5	9.8	7.8	9.5	18	4.7	3.2	6.1	5.3
			R 5	5	4	5	13.9	10.1	19.1	11	0.7	3.7	0.8	3
			L 5	5	4	5	11.6	7.1	24.8	17.4	5	1.4	5.7	5.4

MMT manual muscle testing using Medical Research Council [MRC] grading.

compression at C4–5 and C5–6 with intramedullary signal changes shown by MRI (Fig. 1a). Both nerve root ultrasound examination and CMAP recordings were conducted before and 2 weeks after surgery (Fig. 1b–d). He underwent C4–C6 laminoplasty with good neurological recovery without C5 palsy. He could walk with a cane two weeks after surgery. The numbness in his hand had also improved. The CSA of the C6 nerve root reduced postoperatively without amplitude reduction of the deltoid and biceps muscle (Fig. 1c, d).

DISCUSSION

Morphological change of the cervical nerve root had been observed after spinal cord decompression surgery. Both spinal cord and nerve root are involved in degenerative cervical spine, and radiculopathy in nonmyelopathic degenerative cervical cord compression was reported as a predictor for developing DCM [11]. Thus, nerve root assessment may be useful for evaluating cervical myelopathy in addition to cervical radiculopathy.

Because the time period between the pre- and post-operative examination was within two weeks in this study, the rapid reversible mechanisms such as inflammation and edema [12] conceivably contributed to the nerve root CSA change. Spinal cord decompression improves not only the spinal cord compression itself but also the circulatory condition at and around the compressed spinal cord; the ischemic state or vascular congestion would resolve after spinal cord decompression [13, 14]. Median nerve CSA reduction with pain and numbness improvement after steroid injection for carpal tunnel syndrome was reported [15–17]. And local nerve ischemia, inflammation and vascular congestion

were considered underlying reversible conditions alleviated by the steroid injections [15].

MRI had a limited resolution to delineate the intra-spinal canal cervical nerve roots. In fact, the narrowing of the C4–5 and C5–6 neural foramen on axial MRI displayed no correlation with the CSA of the C5 and C6 spinal nerves. On the other hand, ultrasound examination can directly observe the nerve root at the sulcus of the transverse process. The swollen CSA of cervical nerve roots in cervical radiculopathy [4, 18] and myelopathy [5] were reported in previous cross-sectional studies. In contrast, this study focused on the longitudinal changes. Fifteen out of twenty six C5 nerve roots (57.7%) and fourteen C6 nerve roots (53.8%) showed preoperative CSA enlargement as compared to the reported normal values: C5, $6.7 \pm 2.0 \text{ mm}^2$, and C6, $11.3 \pm 2.9 \text{ mm}^2$ [19]. Sixteen C5 nerve roots (61.5%) and nine C6 nerve roots (34.6%) also showed CSA enlargement postoperatively. Although C6 nerve roots showed a significant reduction of CSA, we observed a varying degree of CSA change in each of the patients before and after surgery. The heterogeneity of cervical degenerative disease presumably explains the results. On the other hand, the deltoid and biceps CMAP amplitude assuming C5 and C6 nerve root motor function showed no significant change with no postoperative C5 palsy between before and after surgery. C6, 7 and 8 nerve roots distributed the dermatome of the hand, whereas C5 nerve root did not [20]. Thus, the significant C6 nerve root CSA change might be associated with hand sensory function improvement.

Cervical radiculopathy and cervical myelopathy are generally considered to be two separate disease entities. However, the distinct lesion site remains to be clarified in some cases; for example, patients presenting with a unilateral upper extremity

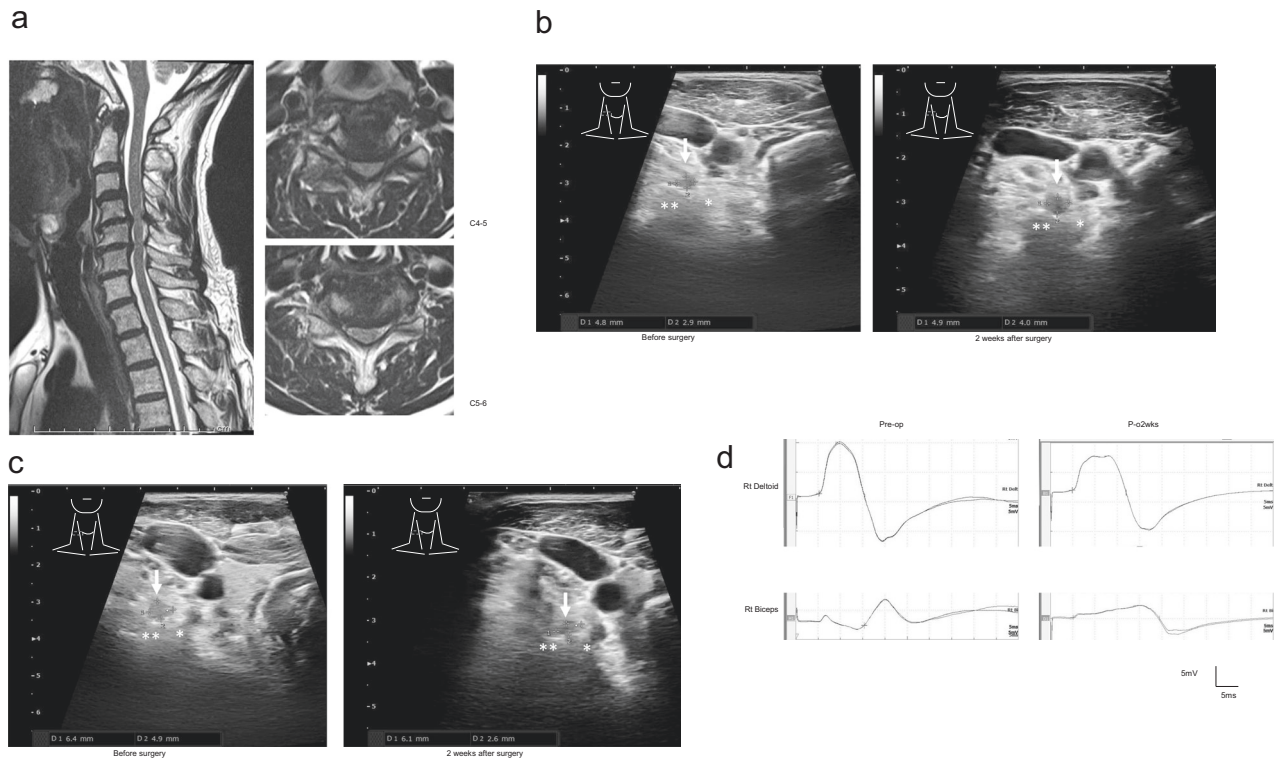


Fig. 1 Patient no. 5: MRI, nerve root US and CMAPs. **a** The left panel shows the mid-sagittal cervical spine MRI. It demonstrates the cord compression with the intramedullary change at C4–5 and C5–6. The right upper and lower panel showed C4–5 and C5–6 axial section, respectively. **b** The left and right panel show the CSA of right C5 nerve root (arrow) before and 2 weeks after surgery, respectively. Asterisks (*) indicate the anterior tubercle of the C5 transverse process. Double asterisks (**) indicate the posterior tubercle of the C5 transverse process. CSA reduction was not exhibited postoperatively. **c** The left and right panel shows the CSA of right C6 nerve root (arrow) before and 2 weeks after surgery, respectively. Asterisks (*) indicate the anterior tubercle of the C5 transverse process. Double asterisks (**) indicate the posterior tubercle of the C5 transverse process. CSA reduction was exhibited postoperatively. **d** The upper left and right panel show the preoperative and postoperative deltoid CMAPs, respectively. The lower left and right panel show the preoperative and postoperative biceps CMAPs, respectively.

weakness concomitant with spinal cord compression such as cervical spondylotic amyotrophy. The lesion site of the postoperative C5 palsy, nerve root and/or spinal cord lesion, is also not settled [21, 22]. This study showed the nerve root morphological changes after spinal cord decompression surgery, that provided us with clues to help clarify the functional connection between spinal cord and nerve root.

Since this study is a small case series and we observed a varying degree of CSA changes in each patient before and after surgery, further investigation is essential to confirm longitudinal changes of nerve roots. In addition, the correlation between sensory recovery and CSA changes had not been evaluated in this study. Spinal cord deformation and the extent of the intramedullary damage also need to be analysed. Moreover, we had no postoperative C5 palsy in this study.

In summary, the CSA of C6 nerve roots significantly reduced after spinal cord decompression, whereas CMAPs of deltoid and biceps showed no significant change between before and after surgery. Independent CSA changes on ultrasound might be useful when conducting a functional evaluation of the postoperative nerve root.

DATA ARCHIVING

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

REFERENCES

- Nouri A, Tetreault L, Singh A, Karadimas SK, Fehlings MG. Degenerative cervical myelopathy: epidemiology, genetics, and pathogenesis. *Spine*. 2015;40:E675–93.
- Meacock J, Schramm M, Selvanathan S, Currie S, Stocken D, Jayne D, et al. Systematic review of radiological cervical foraminal grading systems. *Neuroradiology*. 2021;63:305–16.
- Reza Soltani Z, Sajadi S, Tavana B. A comparison of magnetic resonance imaging with electrodiagnostic findings in the evaluation of clinical radiculopathy: a cross-sectional study. *Eur Spine J*. 2014;23:916–21.
- Takeuchi M, Wakao N, Hirasawa A, Murotani K, Kamiya M, Osuka K, et al. Ultrasonography has a diagnostic value in the assessment of cervical radiculopathy: a prospective pilot study. *Eur Radio*. 2017;27:3467–73.
- Takeuchi M, Wakao N, Kamiya M, Hirasawa A, Murotani K, Takayasu M. Simple presurgical method of predicting C5 palsy after cervical laminoplasty using C5 nerve root ultrasonography. *J Neurosurg Spine*. 2018;29:365–70. <https://doi.org/10.3171/2018.2.SPINE171363>. Epub 2018 Jul 6.
- Japanese Orthopaedic Association Scoring system (17-2) for cervical myelopathy. *Nippon Seikeigeka Gakkai Zasshi. J Jpn Orthop Assoc*. 1994;68:498.
- Compston A. Aids to the investigation of peripheral nerve injuries. Medical Research Council: Nerve Injuries Research Committee. His Majesty's Stationery Office: 1942; pp. 48 (iii) and 74 figures and 7 diagrams; with aids to the examination of the peripheral nervous system. By Michael O'Brien for the Guarantors of Brain. Saunders Elsevier: 2010; pp. [8] 64 and 94 Figures. *Brain: a J Neurol*. 2010;133:2838–44.
- Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15:155–63.
- Kim S, Lee JW, Chai JW, Yoo HJ, Kang Y, Seo J, et al. A New MRI grading system for cervical foraminal stenosis based on Axial T2-Weighted Images. *Korean J Radio*. 2015;16:1294–302.
- Kanda Y. Investigation of the freely available easy-to-use software 'EZ' for medical statistics. *Bone Marrow Transpl*. 2013;48:452–8.
- Kadanka Z Jr, Adamova B, Kerkovsky M, Kadanka Z, Dusek L, Jurova B, et al. Predictors of symptomatic myelopathy in degenerative cervical spinal cord compression. *Brain Behav*. 2017;7:e00797.

- Rydevik B, Lundborg G, Bagge U. Effects of graded compression on intraneural blood flow. An in vivo study on rabbit tibial nerve. *J hand Surg*. 1981;6:3–12.
- Cheng X, Long H, Chen W, Xu J, Huang Y, Li F. Three-dimensional alteration of cervical anterior spinal artery and anterior radicular artery in rat model of chronic spinal cord compression by micro-CT. *Neurosci Lett*. 2015;606:106–12.
- Wu S, Chandoo S, Zhu M, Huang K, Wang Y, Wang Z, et al. Is the cervical anterior spinal artery compromised in cervical spondylotic myelopathy patients? Dual-energy computed tomography analysis of cervical anterior spinal. *Artery World Neurosurg*. 2018;115:e152–9.
- Lee YS, Choi E. Ultrasonographic changes after steroid injection in carpal tunnel syndrome. *Skelet Radio*. 2017;46:1521–30.
- Wang JC, Lin KP, Liao KK, Chang YC, Wang KA, Huang YF, et al. Sonographic median nerve change after steroid injection for carpal tunnel syndrome. *Muscle Nerve*. 2018;58:402–6.
- Cartwright MS, White DL, Demar S, Wiesler ER, Sarlikiotis T, Chloros GD, et al. Median nerve changes following steroid injection for carpal tunnel syndrome. *Muscle Nerve*. 2011;44:25–9.
- Kim E, Yoon JS, Kang HJ. Ultrasonographic cross-sectional area of spinal nerve roots in cervical radiculopathy: a pilot study. *Am J Phys Med rehabilitation/Assoc Academic Physiatrists*. 2015;94:159–64.
- Takeuchi M, Wakao N, Kamiya M, Osuka K, Matsuo N, Terasawa T, et al. Morphological distinction of cervical nerve roots associated with motor function in 219 healthy volunteers: a multicenter prospective study. *Spine*. 2014;39:E944–9.
- McGillicuddy JE. Cervical radiculopathy, entrapment neuropathy, and thoracic outlet syndrome: how to differentiate? Invited submission from the Joint Section Meeting on Disorders of the Spine and Peripheral Nerves, March 2004. *J Neurosurg Spine*. 2004;1:179–87.
- Imagama S, Matsuyama Y, Yukawa Y, Kawakami N, Kamiya M, Kanemura T, et al. C5 palsy after cervical laminoplasty: a multicentre study. *J bone Jt Surg Br Vol*. 2010;92:393–400.
- Yoshihara H, Margalit A, Yoneoka D. Incidence of C5 Palsy: meta-analysis and potential etiology. *World Neurosurg*. 2019;122:e828–37.

AUTHOR CONTRIBUTIONS

NT was responsible for designing the study protocols, conducting the research, analysing data, interpreting results, and writing the paper. QH, YY, HM, and TS were involved in recruiting patients and editing the paper.

FUNDING

This study was supported by the Grant of Japan Orthopaedics and Traumatology Research Foundation No. 395.

COMPETING INTERESTS

The authors declare no competing interests.

ETHICS

We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

ADDITIONAL INFORMATION

Correspondence and requests for materials should be addressed to Toshihiro Sano.

Reprints and permission information is available at <http://www.nature.com/reprints>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.