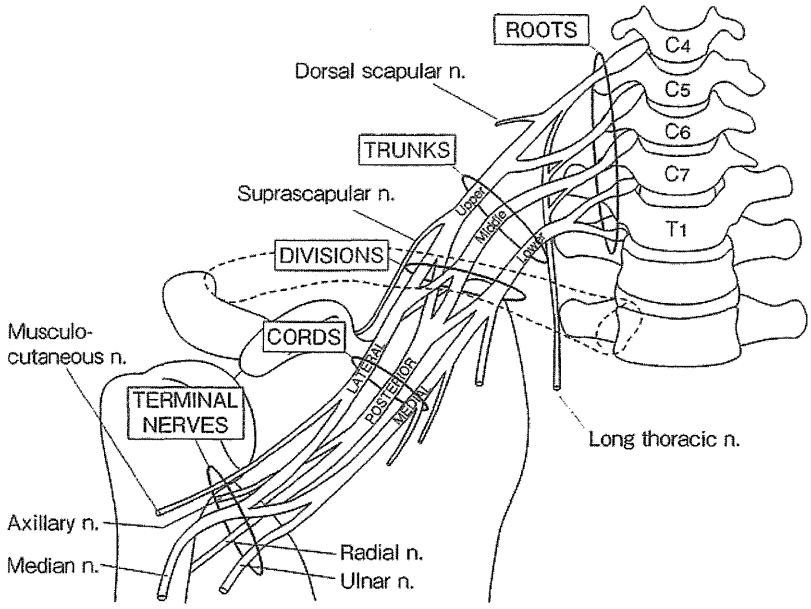

図 2　腕神経叢の解剖
肩甲背神経は腕神経叢からでは C5 根のみで形成されている.

下している場合 C6 髄節障害（前角），亢進している場合 C5 髄節障害（前角）を考える．当科で経験した両側近位型 CSA の 3 症例はすべて前角障害（＋前根障害）であったこともあり，両側の根障害は非常にまれと考えている．

筋力は，三角筋，上腕二頭筋，三頭筋，回外筋，円回内筋，手関節背屈，掌屈，総指伸筋と小指外転筋について少なくとも評価する．腱板断裂との鑑別には，上腕二頭筋と回外筋の評価が重要となる．近位型 CSA では，左右で比較すると必ず上腕二頭筋と回外筋が低下する．一方腱板断裂では正常である．

2．電気生理検査について

1）上肢 CMCT（central motor conduction time：中枢運動伝導時間）

被験者を座位とし，記録電極は小指外転筋（abductor digiti minimi：ADM）の筋腹中央に関電極，筋腱移行部に不関電極を貼付した．尺骨神経を手関節部で最大上に電気刺激し，ADM から CMAPs（M 波）と F 波を導出した．次に ADM に随意収縮を加えた状態で経頭蓋電気刺激し，ADM から MEPs 潜時を導出した．以下の式を用い CMCT を算出した．CMCT＝MEPs 潜時－（[CMAPs 潜時＋F 波潜時-1]/2）.

Kaneko ら[14]は，CMCT は皮質脊髄路障害の有無を判定するのに非常に有用とし，CMCT 正常値を 5.2±1.1 ms と報告した．われわれは，CMCT 6.3 ms 以上は皮質脊髄路障害ありと判断した．服部ら[9]は，頸部脊椎症性ミエロパチーの病態と病型について調査し，錐体路（皮質脊髄路）障害を有する症例はすでに灰白質障害（前角）を有すると報告した．このことから，われわれは CMCT 6.3 ms 以上であれば，前角障害を有する症例と考えた．一方，CMCT 6.3 ms 未満であれば，前根障害と考えた．

2）CMAPs（compound muscle action potentials：複合筋活動電位）

電気刺激点は鎖骨上窩（Erb 点）とし，記録電極は三角筋，上腕二頭筋と三頭筋とした．記録電極について，関電極はいずれも筋腹中央とした．不関電極は三角筋では肩峰，上腕二頭筋では上腕骨外側上顆，上腕三頭筋では肘頭とした．両側三角筋，上腕二頭筋と三頭筋から CMAPs を導出した．振幅は基線から陰性波頂点までとした．

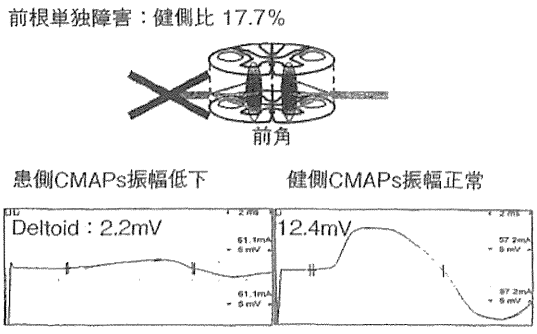

図 3　前根障害における CMAPs 振幅の健側比
前根単独障害では，健側 CMAPs 振幅は 12.4 mV と正常で患側は 2.2 mV と低下し健側比は 17.7% と低かった．これは前根障害の程度を反映している．

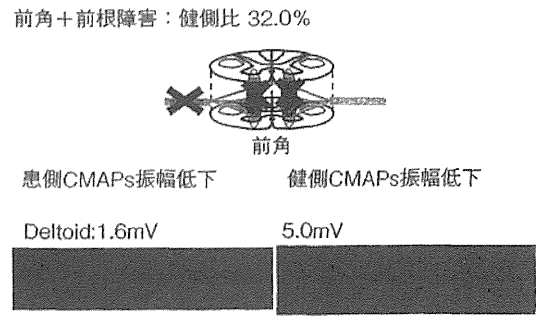

図 4　前角＋前根障害における CMAPs 振幅の健側比
前角＋前根障害では，健側 CMAPs 振幅は 5.0 mV と低く，患側は 1.6 mV とさらに低いが，健側比は 32.0% と前根障害より高くなる．健側 CMAPs 振幅は前角障害の程度を反映している．

CMAPs 振幅は残存した軸索の数を反映するため，予後判定に重要である[17]．

①前根単独障害（CMCT 6.3 ms 未満）の場合

健側の CMAPs 振幅は，正常である．CMAPs 健側比＝患側 CMAPs 振幅/健側 CMAPs 振幅×100 を求めることで，残存した軸索数の割合がわかる（図 3）．

この場合，健側比は前根障害の程度を反映する．そのため，健側比が大きいと予後がよいことが予想され，逆に小さいと予後が悪いことが予想される．

②前角＋前根障害（CMCT 6.3 ms 以上）の場合

健側の筋力が正常であっても CMAPs 振幅が低下している症例は存在する．Sharrard[21]はポリオ患者 7 例の屍体標本から，正常な前角細胞が 40% 以上あれば，筋力は正常であると報告した．つまり，筋力が正常であっても前角障害は存在する．この場合，健側 CMAPs は低下し，subclinical な前角障害の程度を評価することができる．健側比は大きくなり，前根単独障害の症例とは健側比の意味合いが異なる（図 4）．

③前角単独障害（CMCT 6.3 ms 未満）の場合

健側比は前角障害がなければ，根障害の程度を反映する．一方，前角障害があれば，健側 CMAPs 振幅が前角障害の程度を反映し健側比は指標とはなりにくい．健側比を指標とした背景には，健側の CMAPs 振幅はばらつきが大きく指標となりにくいことが問題点としてあったためである[24]．Funaba ら[6,7]は，健常者 88 名の三角筋，上腕二頭筋と三頭筋の CMAPs 振幅正常値を調査し，CMAPs 振幅正常値は同一個体であれば，3 つの筋肉と相関関係あることを報告した．近位型 CSA では健側上腕三頭筋の筋力は正常であることが多く，この健側上腕三頭筋 CMAPs 振幅を用いて以下の式から健側三角筋，上腕二頭筋 CMAPs 振幅を予想し，算出された振幅以下の場合は前角障害と診断した．

上腕二頭筋 CMAPs 振幅＝0.561×上腕三頭筋 CMAPs 振幅＋1.91 mV

三角筋 CMAPs 振幅＝0.52×上腕二頭筋 CMAPs 振幅＋3.29 mV

3）針筋電図

針筋電図は，両側三角筋，上腕二頭筋，上腕三頭筋，大菱形筋，円回内筋，ADM に行った．大菱形筋は C5 根障害，円回内筋は C6 根障害の有無の判定に用いた．大菱形筋から脱神経電位を認めれば C5 が関与していることを確認できる．円回内筋から脱神経電位を認めれば C6 の関与が強いことが理論的に考えられる．

3．画像所見について

MRI と CT myelography では，脊柱管内病変では C3/4，C4/5 高位，椎間孔部病変では C4/5，C5/6 高位について観察し，電気生理検査所見と一

表 1　平均健側比を用いた治療方針

平均健側比	前角＋前根障害	前根単独障害
60%＜	頸椎手術	保存治療
30%＜　＜60%	頸椎手術	頸椎手術 or 保存治療
10%＜　＜30%	頸椎手術＋多数筋移行術	頸椎手術（＋多数筋移行術）
＜10%	頸椎手術＋多数筋移行術	多数筋移行術

致するか確認する．

手術治療方針について

当科では三角筋は主に C5 髄節，上腕二頭筋は主に C6 髄節支配と考えている観点から，平均健側比（三角筋の CMAPs 健側比と上腕二頭筋の CMAPs 健側比の平均）を指標として頸椎術後治療成績を報告してきた[11,12]．

その結果，前根単独障害に対して，平均健側比が 30～60%では頸椎手術もしくは保存的治療，10～30%では頸椎手術のみで改善する症例も存在するが，改善が得られなかった症例に対しては，多数筋腱移行術を追加する．10%未満では頸椎手術のみでは改善は期待できず，多数筋腱移行術を行う．

前角＋前根障害に対して，全例頸椎手術適応と考えている．特に平均健側比が 30%以上では頸椎手術のみで改善を期待でき，よい適応であるが，30%未満では頸椎手術だけでは改善が期待できず，多数筋腱移行術を考慮する必要がある．

前角単独障害に対して，頸椎手術適応と考えている．当科では現在まで 1 例の経験しかないが，頸髄症であるため頸椎手術(椎弓形成のみ)を行った．

頸椎手術について，われわれは電気生理検査から除圧部位を同定し，前根単独障害に対しては前方除圧固定もしくは椎間孔拡大のみ，前角＋前根障害に対しては椎弓形成＋椎間孔拡大もしくは前方除圧固定，前角単独障害に対して椎弓形成を行ってきた．椎弓形成か前方除圧固定かの判断は，脊柱管前後径や側面像での alignment を参考に決定している．また，障害部位を手術しても改善しない症例や悪化する症例（いわゆる術後 C5 麻痺）も存在する．このような症例に対しては，多数筋腱移行術を追加することもある．当科で経験した近位型 CSA 術後 C5 麻痺は 5 例（発生率 15.6%）で頻度が高い．経過観察期間が短い症例もあるが，予後不良の印象である．

多数筋腱移行術は，近位型 CSA は主に C5，C6 障害であるため C5，C6 髄節支配筋以外の筋を移行して肩外転機能と肘屈曲機能を再建する手技である．具体的には，肩外転機能を再建する目的で Bateman 法[1]，肘屈曲機能を再建する目的で Clark 変法[3]を行っている．

Bateman 法は，副神経，C3 と C4 神経支配の僧帽筋上部を肩峰と一塊として上腕骨に螺子固定する方法である[1]．

Clark 法は，外側・内側胸筋神経（C7，C8，T1）支配の大胸筋下部部分を上腕二頭筋腱に縫着する方法である[3]．われわれは，大胸筋が上腕骨に付着する部位を切離する modify した方法で行っている．

これらの方法は，C5，C6 髄節支配筋を使用しない再建法であり，機能改善が大いに期待できる方法である．

まとめ

平均健側比を用いた治療方針を表 1 にまとめる．

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Japanese 2011 nationwide survey on complications from spine surgery

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A running title: Nationwide survey for spine surgery

Biomechanical analysis of cervical myelopathy due to ossification of the posterior longitudinal ligament: Effects of posterior decompression and kyphosis following decompression

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Abstract. Cervical ossification of the posterior longitudinal ligament (OPLL) results in myelopathy. Conservative treatment is usually ineffective, thus, surgical treatment is required. One of the reasons for the poor surgical outcome following laminoplasty for cervical OPLL is kyphosis. In the present study, a 3-dimensional finite element method (3D-FEM) was used to analyze the stress distribution in preoperative, posterior decompression and kyphosis models of OPLL. The 3D-FEM spinal cord model established in this study consisted of gray and white matter, as well as pia mater. For the preoperative model, 30% anterior static compression was applied to OPLL. For the posterior decompression model, the lamina was shifted backwards and for the kyphosis model, the spinal cord was studied at 10, 20, 30, 40 and 50° kyphosis. In the preoperative model, high stress distributions were observed in the spinal cord. In the posterior decompression model, stresses were lower than those observed in the preoperative model. In the kyphosis model, an increase in the angle of kyphosis resulted in augmented stress on the spinal cord. Therefore, the results of the present study indicated that posterior decompression was effective, but stress distribution increased with the progression of kyphosis. In cases where kyphosis progresses following surgery, detailed follow-ups are required in case the symptoms worsen.

Introduction

Ossification of the posterior longitudinal ligament (OPLL) is recognized as a common clinical entity that results in compression myelopathy of the cervical spinal cord. Since conservative treatment for severe myelopathy caused by OPLL is usually ineffective, surgical treatment is selected for the majority of cases. Decompressive surgical procedures for OPLL-associated cervical myelopathy are divided into those using an anterior or a posterior approach. Iwasaki *et al* (1) identified that laminoplasty was effective and safe for the majority of OPLL patients that had an occupying ratio of OPLL <60% and with plateau-shaped ossification. However, neurological outcomes following laminoplasty for cervical OPLL were poor to fair in patients with an occupying ratio of >60% and/or hill-shaped ossification (1). One of the factors associated with poor surgical outcomes following laminoplasty for cervical OPLL is kyphosis (1,2).

Clinical results from patients treated with the posterior approach have been previously reported (1,2). However, to date, there have been no studies focusing on the stress distributions of posterior decompression for cervical OPLL and the effects of kyphosis. In the present study, a 3-dimensional finite element method (3D-FEM) was used to analyze the stress distributions of posterior decompression, as well as kyphosis, in a spinal cord with cervical OPLL and hill-shaped ossification.

Materials and methods

Spinal cord models. Abaqus 6.11 (Dassault Systèmes Simulia Corporation, Providence, RI, USA) finite element package was used for FEM simulation. The 3D-FEM spinal cord model established in this study consisted of gray and white matter, as well as pia mater (Fig. 1). To simplify calculations in the model, the denticulate ligament, dura and nerve root sheaths were not included. The pia mater was included since it has been previously identified that the spinal cord with and without this component shows significantly different mechanical behavior (3). The spinal cord was assumed to be symmetrical around the mid-sagittal plane; therefore, only half the spinal cord required reconstruction and the whole model was integrated by mirror image. For computed tomography-myelography (CTM) measurement, the vertical length of the spinal cord was two vertebral bodies (~40 mm).

The lamina model was established by measuring CTM and magnetic resonance imaging (MRI) and simulated cervical

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Key words: ossification of the posterior longitudinal ligament, cervical myelopathy, finite element method

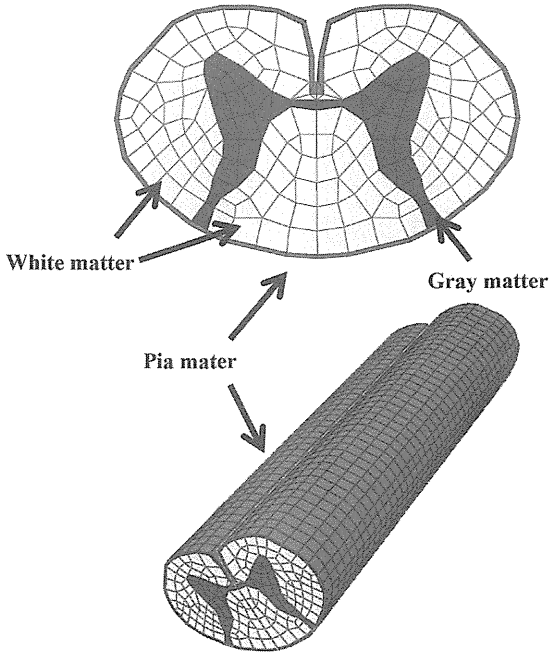

Figure 1. 3D-FEM of the spinal cord consisting of gray matter, white matter and pia mater. 3D-FEM, 3-dimensional finite element model.

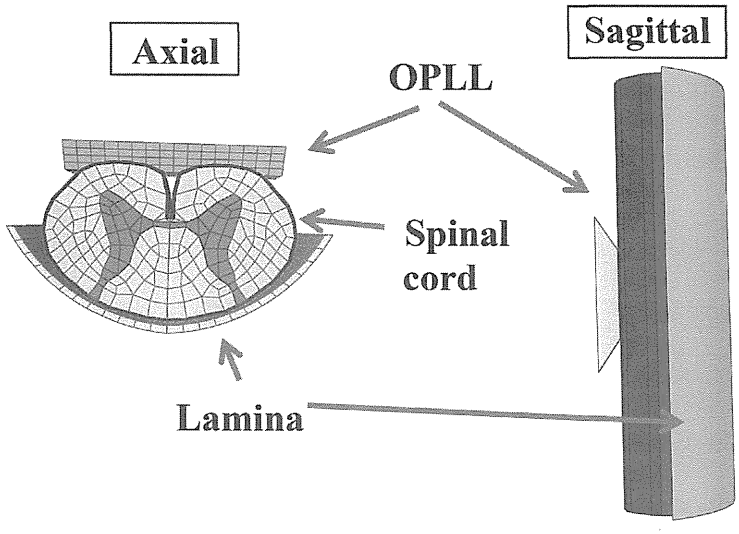

Figure 2. Lamina model with hill-shaped OPLL established at the rear of the spinal cord (axial and sagittal view). OPLL, ossification of the posterior longitudinal ligament.

OPLL. A rigid, wide trapezium body with a slope of 30˚ was used to simulate cervical OPLL by measuring the MRI of paper (Fig. 2) (1).

Mechanical properties. The spinal cord consists of three distinct materials referred to as white matter, gray matter and pia mater. The mechanical properties (Young's modulus and Poisson's ratio) of the gray and white matter were determined using data obtained by the tensile stress strain curve and stress relaxation under various strain rates (4,5). The mechanical properties of pia mater were obtained from previous literature (6). The mechanical properties of hill-shaped ossification and lamina were stiff enough for the spinal cord to be pressed. Based on the assumption that no slippage occurs at the interfaces of white matter, gray matter and pia mater, these interfaces were glued together. Since there are no data on the friction coefficient between the lamina and spinal cord, this was assumed to be frictionless. Similarly, the coefficient of friction between the hill-shaped ossification and spinal cord was assumed to be frictionless at the contact interfaces.

The spinal cord, hill-shaped ossification and lamina model were symmetrically meshed with 20-node elements. The total number of isoparametric 20-node elements was 11,542 and the total number of nodes was 66,513.

Compression. In a biomechanical study of static compression of cervical myelopathy due to OPLL, Kato *et al* (7) reported that a critical point may exist between 20 and 40% compression of the anterior-posterior diameter of the spinal cord. For the preoperative model, compression was simulated by cervical

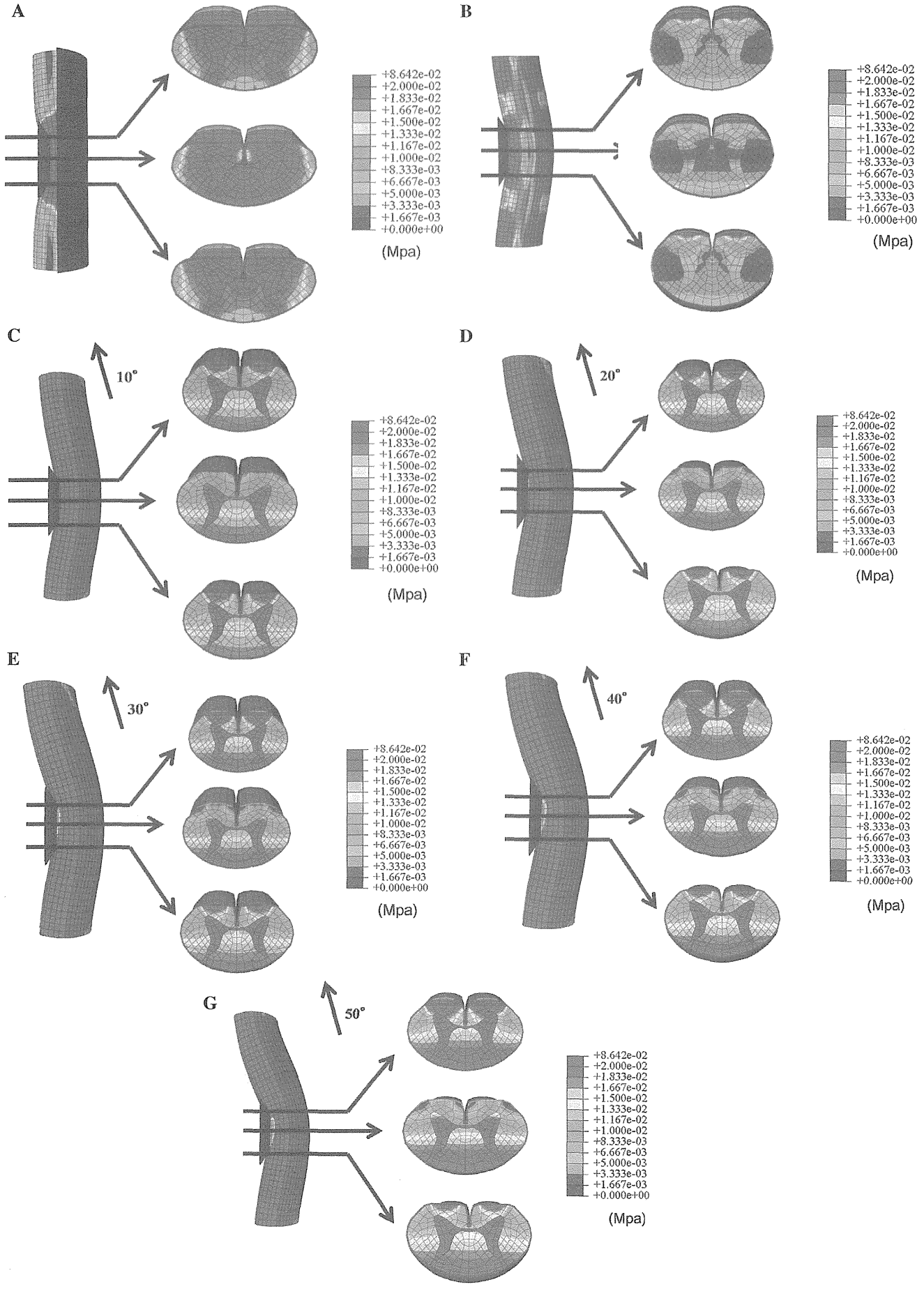

Figure 3. Stress distributions under proximal, central and distal anterior compression of the spinal cord by OPLL are shown in the (A) preoperative, (B) posterior decompression and (C-G) kyphosis models at 10, 20, 30, 40 and 50° kyphosis. OPLL, ossification of the posterior longitudinal ligament.

OPLL with hill-shaped ossification. The lamina was fixed in all directions and 30% anterior static compression of the anterior-posterior diameter of the spinal cord (median, 20-40%) was applied by OPLL (1,7). For the posterior decompressive model, the lamina was shifted back to prevent contact with the spinal cord under the application of anterior static compression. For the kyphosis model, the spinal cord was studied at 10, 20, 30, 40 and 50˚ kyphosis. The extent of stretching the spinal cord was 20% of the length of the spinal cord indicated in a previous study (8).

In total, seven compression combinations were evaluated and in each cross-section the average von Mises stress was recorded the color-coded made for each stress in the spinal cord.

Results

Stress distribution in the three models. In the preoperative model, high stress distributions were observed in all axial levels of the spinal cord following anterior static compression (30% of the anterior-posterior diameter of the spinal cord) by cervical OPLL with hill-shaped ossification (Fig. 3A).

In the posterior decompression model, stresses from anterior compression of the spinal cord were lower compared with those observed in the preoperative model. However, stresses in the anterior funiculus slightly increased (Fig. 3B).

For the kyphosis model, stress distribution increased in the anterior funiculus, posterior funiculus and the gray matter in proximal and distal OPLL. The stress distribution also increased in the posterior funiculus and the gray matter in the center of OPLL. Furthermore, increasing the angle of kyphosis resulted in increased stress on the spinal cord (Fig. 3C-G).

Discussion

The development of myelopathy significantly affects the prognosis of patients with OPLL in the cervical spine. Cervical OPLL is treated by anterior decompression and spinal fusion or laminoplasty. Tani *et al* identified that postoperative neurological deterioration occurred following posterior surgery. The authors indicated that one of factors of neurological deterioration affectedto decrease in the lordosis of the cervical spine (9).

Masaki *et al* reported that patients with a poor outcome following laminoplasty showed larger segmental mobility of the vertebrae prior to and following surgery. The authors hypothesized that laminoplasty in patients with massive OPLL may not lead to sufficient posterior shift of the spinal cord, resulting in persistent anterior impingement of the spinal cord by OPLL. In cases where substantial segmental mobility remains following surgery, it is possible that damage to the injured spinal cord continues to progress (10).

Iwasaki *et al* reported that a postoperative change in cervical alignment was observed in 18% of cases. Their study indicated that postoperative changes in cervical alignment may be a reflection of dynamic instability. A poor surgical outcome following laminoplasty was indicated by newly developed cervical kyphosis (1).

Using this prior knowledge, the present study investigated whether the development of kyphosis of the spinal cord following anterior compression was associated with changes in stress distribution. The aim was to develop a 3D-FEM spinal cord model that simulated the clinical situation and analyzed the clinical condition of the patient. Similarly to previous studies by Kato *et al* (7,11,12), Li *et al* (13,14) and Nishida *et al* (15,16), bovine spinal cord was used in the current analytical model since it was impossible to obtain fresh human spinal cord. The mechanical properties of the spinal cord used in the present study were similar to those used in earlier studies (4-6). Li *et al* identified that it was reasonable to use the mechanical properties of the bovine spinal cord since the brain and spinal cord of cattle and humans show similar injury changes (14). For the purpose of the present study, it was therefore assumed that the mechanical properties of the spinal cord from these two species were similar. Persson *et al* (3) reported on the division of the spinal cord into pia mater and white and gray matter. The authors demonstrated that the presence of pia mater had a significant effect on spinal cord deformation. Therefore, pia mater was included in the current model in order to accurately simulate the clinical situation.

In the present study, stress distribution in the spinal cord increased following static compression by cervical OPLL with hill-shaped ossification. Stress distribution in the spinal cord decreased in the posterior decompression model, demonstrating the effectiveness of this approach. However, in the kyphosis model, stress distribution increased with increased angles of kyphosis. Thus, when segmental mobility remains and cervical alignment changes following posterior decompression, damage to the spinal cord and the progression of symptoms are likely to occur.

In conclusion, stress analyses were conducted in models of preoperative compression, posterior decompression and kyphosis following posterior decompression by cervical OPLL with hill-shaped ossification.

Posterior decompression was shown to be effective, however, stress distribution increased with the progression of kyphosis, indicating that symptoms are likely to worsen. In cases where kyphosis has progressed following surgery, particularly those in which the angle of kyphosis is large, detailed follow-ups should be conducted in case the symptoms worsen.

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Spinal Cord (2013), 1–6

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ORIGINAL ARTICLE

Preoperative diagnosis of the responsible level in CCM using CMAPs: comparison with SCEPs

M Funaba, T Kanchiku, Y Imajo, H Suzuki, Y Yoshida and T Taguchi

Study design: A retrospective study.
Objective: To elucidate the correlation between compound muscle action potentials (CMAPs) amplitudes and responsible level of compressive cervical myelopathy (CCM), and the accuracy of level diagnosis by using CMAPs.
Setting: This study was conducted at the Department of Orthopedic surgery, Yamaguchi University Graduate School of Medicine, Japan.
Method: A total of 28 patients with CCM were investigated in this study. Erb's point-stimulated CMAPs were measured from deltoid, biceps, triceps in all patients as compared with 88 healthy subjects. We performed a level diagnosis on the basis of CMAPs amplitudes. We performed a level diagnosis on the basis of CMAPs amplitudes and using an index that measures the deviation of CMAPs amplitudes between triceps and deltoid or biceps.
Results: Significant correlations between the mean CMAPs amplitudes and responsible level were showed for deltoid (6.82 ± 2.33 mV) at C3/4 ($P<0.01$) and biceps (8.75 ± 4.42 mV) at C4/5 ($P=0.015$). Despite considerable individual variability in CMAP amplitudes, there were correlations among CMAPs amplitudes for deltoid, biceps and triceps in the same individual. The sensitivity was 75.0%, specificity 75.0% in the index for diagnosis of C3/4. The sensitivity was 75.0%, specificity 66.7% in the index for diagnosis of C4/5.
Conclusion: This study showed small CMAPs amplitudes in the deltoid indicated a C3/4 level of myelopathy and in biceps at the C4/5 level and could help exclude clinically silent cord compression and determine the surgical procedure to the suitable level of concern.
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Keywords: compound muscle action potentials; spinal cord-evoked potentials; cervical compressive myelopathy; level diagnosis; involvement of cord segment

INTRODUCTION

Magnetic resonance imaging (MRI) can be used to demonstrate compression of the spinal cord and has an important role for level diagnosis in cases with compressive myelopathy. However, MRI can show abnormal findings despite clinically asymptomatic presentation and therefore it is difficult to determine the responsible level in patients with multilevel spinal compression, as, for example, in elderly people. Ossification of the posterior longitudinal ligament may also occur at several vertebral levels during spinal cord compression, but not all levels compressed by the ossification of the posterior longitudinal ligament lead to symptomatic spinal cord compression. Spinal cord-evoked potentials (SCEPs) are useful for investigating the functional integrity of the spinal cord, in spite of MRI evidence of compression at several levels.[1,2]

We also reported compound muscle action potential (CMAPs) amplitudes that were lower than normal values indicated the involvement of anterior horns.[3] However, there have so far been no reports that correlated the responsible level of cervical myelopathy (CCM) with CMAPs amplitudes.

We hypothesized that preoperative measurement of CMAPs could be used for level diagnosis of CCM. In the present study, we correlated CMAPs amplitudes with the responsible level in an attempt to provide preoperative level diagnosis.

MATERIALS AND METHODS

Patients

A total of 28 patients with CCM (18 with cervical spondylotic myelopathy and 10 with ossification of the posterior longitudinal ligament) were determined by intraoperative SCEPs to have a single site of conduction abnormalities at the intervertebral level. Eighteen were men and 10 were women and their average age was 70.8 years (range; 48–86). All patients underwent cervical laminoplasty. Written informed consent with the approval of Yamaguchi University Graduate School of medicine was obtained for preoperative MRI investigation and electrophysiological studies in all patients. Those who fulfilled the following criteria were included in the study.

A diagnosis of myelopathy was established based on the presence of hyperreflexia, including a positive Hoffmann sign, upper extremity sensory disturbance and obvious MRI-documented cervical spinal cord compression. Sensory and motor nerve conduction velocities in the peripheral nerves were within normal limits.

Patients who had peripheral neuropathy and concomitant radiculopathy were excluded.

Normative data

Thirty-nine male and forty-nine female subjects (average age 54.3 years, age range 23–91 years) with no history of injury or pathology of the upper limb were studied. They were submitted to a medical examination consisting of a detailed history regarding motor and sensory upper limb symptoms, followed

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by thorough physical examination. Exclusion criteria were a history of upper limb symptoms, glove and stocking sensory symptoms, diabetes mellitus, any form of medication and abnormal tendon reflexes or sensory and motor examination.

Magnetic resonance imaging

All patients underwent MRI with a 1.5-tesla imaging system. Sections were 5-mm thick, with a 2-mm gap between intersections. T1-weighted and T2-weighted sagittal and axial imaging were obtained.

Electrophysiological investigation

Erb's point-stimulated CMAPs. All electrophysiological examinations were performed using a Nicolet Viking 4 instrument. Erb's point-stimulated CMAPs were recorded in the deltoid, biceps brachii (biceps), and triceps brachii (triceps) muscles in all subjects. An 11 mm diameter disc (Dantec 13L 29, Dantec Medical, Skovlunde, Denmark) was placed over the middle of the deltoid as an active electrode, on the acromion as a reference electrode in the deltoid, over the middle of the biceps muscle as an active electrode and on the lateral epicondyle of humerus as a reference electrode in the biceps muscle, and over the middle of the triceps muscle as an active electrode and on the olecranon as a reference electrode in the triceps muscle. The skin was prepared with an abrasive solution to reduce impedance and a ground strap was wrapped around the elbow. The bipolar stimulator probe (Nicolet S403, Natus Medical, San Carlos, CA, USA) provides a pair of bare metal contacts, 3 mm in diameter and with an adjustable inter-electrode distance which was set to 25 mm in our study. The stimulus intensity was gradually increased until it no longer altered the size of the recorded response. Measurement of CMAPs included the negative-peak amplitude from baseline to peak. Average amplitudes for CMAPs were calculated for both sides. The amplitude ratio was calculated by dividing the response from one side by the other and multiplying by 100.

Recording of SCEPs for diagnosis of symptomatic lesion

SCEPs after median nerve stimulation (MN-SCEPs), transcranical electric stimulation (TES-SCEPs), and spinal cord stimulation (Spinal-SCEPs) were recorded intraoperatively. The median nerves were stimulated (square wave pulse, 0.2-ms duration, 3-Hz rate) at the wrist with the cathode placed proximally. The stimulus intensity was set at 1.5 times for producing the thumb twitch in an awakened condition. TES was delivered as square pulses of 0.2 ms duration and at an intensity of 100 mA through needle electrodes (13R25, length 8 mm, diameter 0.8 mm; Dantec, Skovlunde, Denmark) placed on the skull. The anode was placed 7 cm laterally to the right of the vertex on line joining the external auditory meatus. The cathode was placed on the opposite side. Spinal-SCEPs were delivered by an epidural catheter electrode (UKG-100-2PM, diameter 0.8 mm, length 900 mm, Unique Medical Corporation, Kobe, Japan) inserted into the dorsal epidural space from the C7-T1 and T11-T12 interlaminar space. Square wave pulse (0.2 ms duration, 3-Hz rate) was delivered at an intensity of 15–20 mA. Before laminoplasty, all SCEPs were recorded intraoperatively with recording electrodes (13R25) inserted in the ligamentum flavum at each interlaminar space. A reference electrode was inserted into the subcutaneous tissue in the posterior aspect of the neck for the recording of MN-SCEPs and Spinal-SCEPs. A bipolar recording method was used (active proximal and reference distal) for the recording of TES-SCEPs. All SCEPs signals were amplified and filtered with a bandpass of 20 to 3000 Hz using a standard evoked potential/electromyography machine (Nicolet Viking, Natus Medical). Average of 100 to 200 MN-SCEPs, 40–60 TES-SCEPs and 20–30 spinal-SCEPs responses were obtained. Two different averaged responses were superimposed and displayed. In MN-SCEPs, abnormality was determined from the amplitude ratio of spinal responses at each intervertebral level to that recorded at the C6/7 intervertebral level as reported earlier.[4] In TES-SCEPs and Spinal-SCEPs, intervertebral levels with a marked reduction in size of the negative peak (reduction of $>50\%$) were considered as significant (Figure 1).[5]

Preoperative level diagnosis using CMAPs

Studies on the level diagnosis for CCM have shown the C5 motor segment in the spinal cord to be at the level of the C3/4 disc and the C6 motor segment at the level of the C4/5 disc. We have previously reported that C5 and C6 nerve roots are distributed to the deltoid and biceps muscle, with the deltoid predominantly innervated by the C5 nerve root and the biceps by the C6 nerve root.[6,7] We hypothesized the main myotomal distribution was as follows: deltoid in C5 cord segment, biceps in C6 and triceps in C7. If the preoperative CMAPs amplitudes in deltoid were smaller than the normal limits, the responsible level was estimated to be C3/4. This meant that the C5 cord segment was involved. In the same way, if the CMAPs in biceps were smaller, we estimated the responsible level to be C4/5 and this meant the C6 cord segment was involved. We used CMAPs in deltoid and biceps on the affected side and in triceps on the normal side. As described further below, CMAPs amplitudes in triceps correlated with CMAPs amplitudes in the deltoid and biceps. On the basis of this correlation, we designed an index for level diagnosis. When the observed CMAPs amplitudes in the deltoid or biceps were lower than those extrapolated from the CMAPs amplitudes in triceps, this was an indication of C3/4 or C4/5 myelopathy (Table 1).

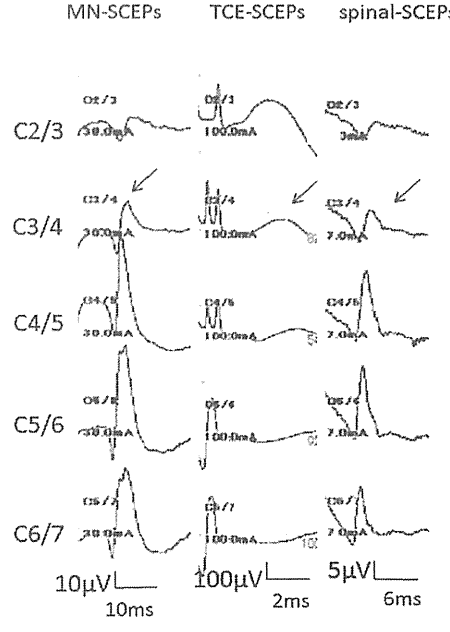

Figure 1 SCEPs obtained from patients with compressive cervical myelopathy. MN-SCEPs demonstrate marked attenuation of amplitude at the C3/4 intervertebral level. TCE-SCEPs also show marked attenuation of amplitude at the C3/4 level. Spinal-SCEPs also show marked attenuation of amplitude at the C3/4 level. The marked attenuation of amplitudes at C3/4 in all SCEPs indicates a conduction block at C3/4. MN-SCEPs, spinal cord-evoked potentials following median nerve stimulation; TCE-SCEPs, spinal cord-evoked potentials following TES; Spinal-SCEPs, spinal cord-evoked potentials following spinal cord stimulation.

Table 1 The index for electrophysiological level diagnosis

Responsible level	*Index for level diagnosis*
C3/4	(D-CMAPs-3)/T-CMAPs
C4/5	(B-CMAPs-4)/T-CMAPs

Abbreviations: CMAPs, compound muscle action potentials; D-CMAPs, CMAPs amplitudes in deltoid (mV); B-CMAPs, CMAPs amplitudes in biceps (mV); T-CMAPs, CMAPs amplitudes in triceps (mV); D-CMAPs-3 divided T-CMAPs are index for the diagnosis of C3/4 myelopathy; B-CMAPs-4 divided T-CMAPs are index for the diagnosis of C4/5 myelopathy.

Statistical analysis

Descriptive statistics, including the mean and standard deviation (s.d.), were applied to each CMAPs value. Related on sex and age factors in CMAPs amplitudes were analyzed. Regression analysis was used to evaluate the correlation among CMAPs amplitudes for the different muscles. (Dependent variables: CMAPs amplitudes in the deltoid- or biceps-independent variable: CMAPs amplitudes in triceps) The Mann–Whitney *U* test was used for unpaired data. The cutoff points for CMAPs amplitudes or for the index were selected by receiver-operating characteristic curve analysis. Receiver-operating characteristic curves were also used to calculate the sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of the preoperative diagnosis corresponding to each intervertebral level. All *P*-values <0.05 were regarded as statistically significant. The free software program R version 2.14 (http://www.r-project.org/) was used for statistical analysis.

RESULTS

Normative data

The normal value (mean ± s.d.) for CMAPs in the deltoid muscle was 10.44 ± 2.18 mV amplitude (range 6.17–16.7), in biceps it was 10.83 ± 2.65 mV (4.79–17.18) and in triceps it was 12.59 ± 3.25 mV (4–21.3). Each amplitude showed large variation. Amplitudes in all muscles decreased with advancing age, but these correlations were weak (deltoid: $R^{*2}=0.13$; biceps: $R^{*2}=0.05$; triceps; $R^{*2}=0.01$; where R^{*2} is the coefficient of determination adjusted for degree of freedom). Compared with women (mean age 53 years, $n=49$), men (mean age 55 years, $n=39$) showed significantly higher amplitude in all three muscles (deltoid: 11.5 ± 2.15 mV vs 9.6 ± 1.81 mV, $P<0.01$; biceps: 12.21 ± 2.65 mV vs 9.73 ± 2.09 mV, $P<0.01$; triceps: 14.15 ± 3.45 mV vs 11.36 ± 2.49 mV, $P<0.01$).

The ratio between deltoid and biceps (D/B) amplitude was 99 ± 18%, between biceps and triceps (B/T) 88 ± 18% and between deltoid and triceps (D/T) 86 ± 20%. These ratios did not show age-related differences (D/B: $R^{*2}=-0.008$; B/T: $R^{*2}=0.01$; D/T: $R^{*2}=0.04$) or gender differences (D/B: $P=0.26$; B/T: $P=0.78$; D/T: $P=0.50$). For each muscle, regression analysis was used to express the amplitudes as a correlation coefficient (Figures 2a and b). CMAPs amplitudes in deltoid or biceps could therefore be estimated from CMAPs amplitudes in triceps, regardless of age or gender. Normative data for CMAPs values are summarized in Table 2.

Magnetic resonance imaging

MRI showed multiple compressions in 26 patients (92.8%). Details were shown in Table 4.

CMAPs of patients with CCM

The level of conduction abnormalities was C3/4 in 16 cases and C4/5 in 12 cases by monitoring SCEPs intraoperatively. Table 3 shows the responsible level estimated from SCEPs and CMAPs amplitudes of deltoid, biceps and triceps, whereas Table 4 shows the mean CMAPs amplitude at each responsible level.

In patients with C3/4 myelopathy, the CMAPs amplitudes of deltoid were 6.82 ± 2.33 mV (mean ± s.d.) ($P<0.0001$) and those

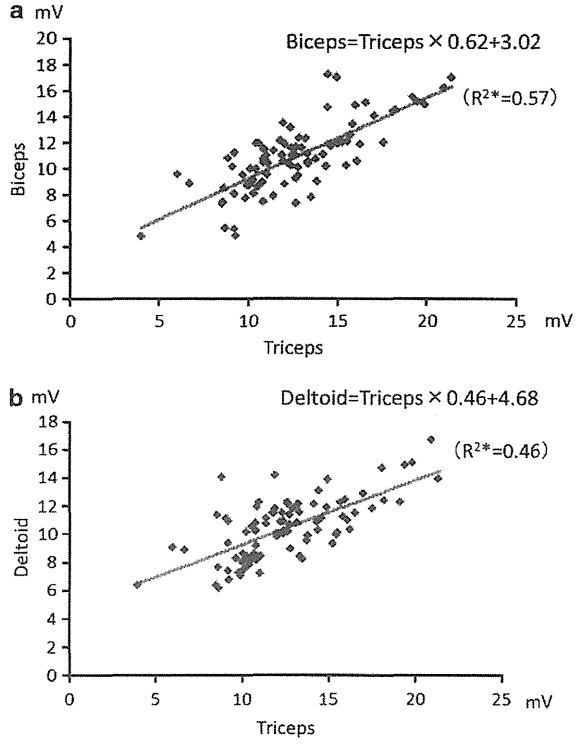

Figure 2 Regression analysis was used to express the amplitudes as a correlation coefficient for deltoid, biceps barchii and triceps brachii. The formulae used for this were: (a) biceps brachii amplitude B = triceps brachii amplitude (T) × 0.62 − 3.02 mV ($R^{*2}=0.57$), (b) deltoid amplitude D = T × 0.46 + 4.68 mV ($R^{*2}=0.46$) (R^{*2}, the coefficient of determination adjusted for degree of freedom).

Table 2 Normative date of CMAPs amplitudes and the ratio among deltoid, biceps and triceps

Muscles	*All subjects*	*CMAPs amplitudes (mV)*	
		Men	*Women*
Deltoid	10.44 ± 2.18	11.50 ± 4.64	9.60 ± 3.26
Biceps brachii	10.83 ± 2.65	12.22 ± 7.05	9.73 ± 4.35
Triceps brachii	12.59 ± 3.25	14.15 ± 11.91	11.36 ± 6.21
	Ratio (%)		
Deltoid/biceps	98.8 ± 17.9	95.99 ± 16.2	101.14 ± 19.0
Biceps/triceps	87.91 ± 18.79	87.88 ± 14.17	87.93 ± 20.1
Deltoid/triceps	85.9 ± 20.09	83.8 ± 17.19	87.57 ± 22.16

Abbreviation: CMAPs, compound muscle action potentials.

Table 3 CMAPs amplitudes with patients of CCM as compared with normal values

CMAPs (mV)	*Responsible level*		
	All (n = 28)	*C3/4 (n = 16)*	*C4/5 (n = 12)*
Deltoid	7.55 ± 2.88	6.82 ± 2.33	8.52 ± 3.34
	$P<0.01$	$P<0.0001$	$P=0.11$
Biceps brachii	9.14 ± 3.55	9.43 ± 2.85	8.75 ± 4.42
	$P<0.01$	$P=0.10$	$P=0.015$
Triceps brachii	12.50 ± 3.54	12.69 ± 3.59	12.51 ± 3.61
	$P=0.94$	$P=0.89$	$P=0.97$

Abbreviations: CMAPs, compound muscle action potentials, CCM, compressive cervical myelopathy.

Table 4 Detail of the 28 patients with cervical compressive myelopathy

Case	*Age*	*Gender*	*Disease*	*The level of conduction abnormalities*	*CMAPs amplitudes (mV)*			*MRI (cord indentation and/or deformed cord)*			
					Deltoid	*Biceps*	*Triceps*	*C3/4*	*C4/5*	*C5/6*	*C6/7*
1	72	F	OPLL	C3/4	7.6	11.68	9.8	+	+	+	
2	54	M	OPLL	C3/4	8.4	12.3	16.6	+	+	+	+
3	77	M	CSM	C3/4	8.3	13.2	15.8	+			
4	59	M	OPLL	C3/4	5.3	9.1	12.8	+		+	+
5	63	F	OPLL	C3/4	8.73	9.41	12.57	+	+	+	
6	78	F	CSM	C3/4	5.61	9.08	12.91	+	+	+	+
7	70	M	OPLL	C3/4	6.92	10.16	14.05	+		+	
8	82	F	CSM	C3/4	3.19	6.01	9.56	+		+	+
9	71	F	CSM	C3/4	5.51	6	8.85	+		+	+
10	71	F	CSM	C3/4	6.17	6.99	11.35	+	+	+	
11	79	M	CSM	C3/4	2.48	7.61	9.07	+	+	+	
12	82	F	CSM	C3/4	6	5.04	8.52	+		+	+
13	84	M	CSM	C3/4	5.17	7.03	9.3	+	+		
14	68	M	OPLL	C3/4	11.04	11.22	19.29	+	+	+	
15	63	M	OPLL	C3/4	10	14.78	19.5	+	+	+	+
16	86	M	CSM	C3/4	8.64	11.35	13.03	+		+	
17	75	M	OPLL	C4/5	4.1	3.4	8.8		+	+	
18	66	F	CSM	C4/5	12.25	8.62	14.2	+	+	+	
19	48	M	CSM	C4/5	11.4	16.4	17.4		+	+	
20	68	M	CSM	C4/5	10.1	6.6	12.5		+	+	
21	84	F	CSM	C4/5	5.32	4.22	6.12		+		
22	56	M	OPLL	C4/5	9.58	14.25	14.34		+	+	
23	67	M	CSM	C4/5	6.5	7.55	11.99	+	+	+	+
24	70	M	OPLL	C4/5	5.54	7.23	8.62	+	+	+	+
25	69	M	CSM	C4/5	11.32	15.83	18.28		+	+	+
26	85	M	OPLL	C4/5	3.28	4.61	10.04	+	+	+	+
27	70	M	CSM	C4/5	10.6	7.7	13.6	+	+	+	
28	66	F	CSM	C4/5	12.3	8.6	14.2		+	+	

Abbreviations: CMAPs, compound muscle action potentials; CCM, compressive cervical myelopathy; CSM, cervical spondylotic myelopathy; F, female; MRI, magnetic resonance imaging; M, male; OPLL, ossification of the posterior longitudinal ligament.
The level of conduction abnormalities was determined by the spinal cord-evoked potentials.

of biceps were 9.43 ± 2.85 mV ($P = 0.10$). In patients with C4/5 myelopathy, the CMAPs amplitudes of deltoid were 8.52 ± 3.34 mV ($P = 0.11$) and those of biceps were 8.75 ± 4.42 mV ($P = 0.015$). There were no statistically significant differences between the mean CMAPs amplitudes in triceps of C3/4 ($P = 0.89$) or C4/5 ($P = 0.97$) myelopathy patients and the normal values.

The most discriminative cutoff value for CMAPs amplitudes in the deltoid for the diagnosis of C3/4 myelopathy was 8.73 mV, giving an area under the curve value of 0.671 (95% confidence interval, 0.44–0.90). This resulted in a sensitivity of 87.5%, specificity of 57.3%, PPV of 73.2% and NPV of 77.5%. The most discriminative cutoff value using the index for diagnosis of C3/4 myelopathy was 0.52, with an area under the curve value of 0.750 (95% confidence interval, 0.55–0.95) and a sensitivity of 75.0%, specificity of 75.0%, PPV of 80.0% and NPV of 69.2% (Figure 3).

The most discriminative cutoff value for CMAPs amplitudes in biceps for the diagnosis of C4/5 myelopathy was 8.62 mV, giving an area under the curve value of 0.594 (95% confidence interval, 0.35–0.83) and a sensitivity of 62.5%, specificity of 75%, PPV of 73.2% and NPV of 77.5%. The most discriminative cutoff value using the index for diagnosis of C4/5 myelopathy was 0.325, with an area

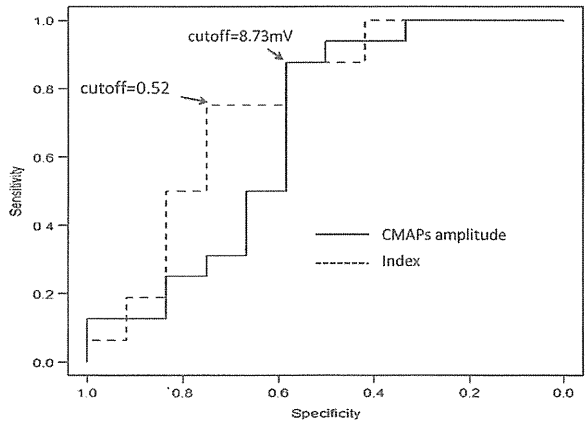

Figure 3 The receiver-operating characteristic (ROC) analysis was performed on the patients with C3/4 myelopathy yielded 0.75 (95% confidence interval (CI), 0.55–0.95) for an area under the curve (AUC) value for the index. (The sensitivity is 75.0% and specificity is 75.0%). CMAPs amplitude in the deltoid had 0.67 (95% CI, 0.44–0.90) for an AUC. (The sensitivity is 87.5% and specificity is 57.3%).

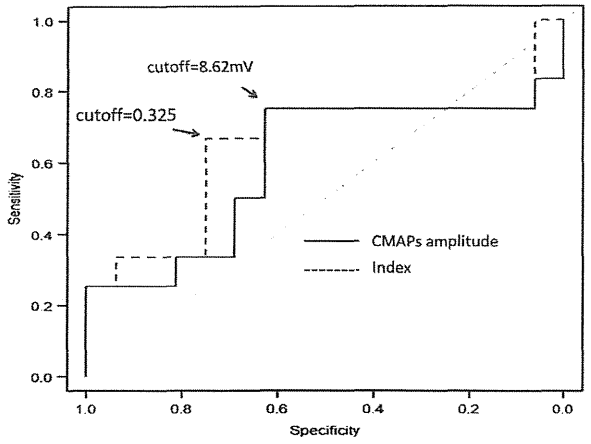

Figure 4 The ROC analysis was performed on the patients with C4/5 myelopathy yielded 0.65 (95% CI, 0.41–0.88) for an AUC for the index. (The sensitivity is 75.0% and specificity is 66.7%). CMAPs in biceps had 0.59 (95% CI, 0.35–0.83) for an AUC. (The sensitivity is 62.5% and specificity is 75%).

under the curve value of 0.646 (95% confidence interval,0.41–0.88) and a sensitivity of 75.0%, specificity of 66.7%, PPV of 62.8% and NPV of 78.1% (Figure 4).

DISCUSSION

CMAPs amplitudes obtained by stimulating below the lesion after injury determine the degree of axonal loss and thus allow for an accurate assessment of prognosis.[8] However, we reported that small CMAP amplitudes indicated not only the involvement of ventral nerve roots but also that of anterior horns with proximal-type cervical spondylotic amyotrophy.[3] Ito *et al.*[9] reported a common pattern for lesion progression in cervical spondylotic myelopathy that involved initial atrophy and neuronal loss in the anterior horn and intermediate zone, followed by degeneration of the lateral and posterior funiculus. MN-SCEPs are mediated by the lateral part of posterior columns, TES-SCEPs by the lateral corticospinal tract and spinal-SCEPs by medial parts of the posterior columns.[10] In the current patient series all SCEPs showed abnormalities, thus indicating the involvement of anterior horns. Small CMAPs amplitudes corresponding to compressed cord segments (deltoid, C3/4 and biceps, C4/5) also showed involvement of the anterior horns, but could not detect the involvement of the long tract. We confirmed that CMAPs amplitudes were better suited for assessing involvement of the anterior horns.

Level diagnosis for CCM is performed by investigating the muscle weakness, deep tendon reflex and sensory disturbance. The sensitivity of muscle weakness tends to be low, but its specificity is high,[11] such that muscle weakness is not detected in mild cases. Cadaver dissection has revealed a close correlation between anterior horns and vertebral bodies;[12] however, the anatomical features make it difficult to give a level diagnosis for CCM. In this respect, muscle weakness resulting from involvement of the anterior horn would be more accurate than sensory disturbance from the posterior horn. The accuracy of level diagnosis using CMAPs was about 70% and it is equivalent to the result of previous reports.[11] However, we confirm that deltoid and biceps are innervated by both C5 and C6 motor segments and these have dominance to innervate muscles, it is difficult to clearly discriminate the nerve domination of C5 and C6. Therefore, it would also be difficult to clearly discriminate between C3/4 myelopathy and C4/5 myelopathy through the monitoring of CMAPs amplitudes. This point is included as the limitations of our study.

Sharrard[13] reported from a study of cadavers with poliomyelitis that more than 40% of anterior horn cells maintained normal muscle strength. If more than 60% of the anterior horn cells were involved this lead to muscle weakness. Patients with a single responsible level of myelopathy do not show clinical muscle weakness because multiple anterior horns innervate the muscle. Small CMAPs amplitudes could indicate subclinical muscle weakness and implicate the involvement of anterior horns in a quantitative manner.

Wee[14] reported that there are good correlation between the CMAPs amplitudes and the muscle bulk in biceps. Therefore, CMAPs amplitudes show considerable individual variation as well as gender and age differences. However, side to side differences in the same individual are much smaller.[15] The distribution of muscle volume in the upper limb was highly conserved across normal subjects, as assessed by MRI.[16] The conserved distribution of muscle volume probably accounts for the correlation of CMAPs amplitudes among the muscles of the upper extremity. The correlations among CMAPs amplitudes for deltoid, biceps and triceps in the same individual may be explained as follows. When CMAPs amplitudes are higher or lower than normal values in patients with large or small muscle volumes, they would be determined as false negative or false positive. The index we designed was therefore more accurate than CMAPs amplitudes, regardless of patient age or gender.

With advancing age, MRI tends to show multiple compression but the responsible level shifts from C5/6 to C3/4 or C4/5.[17] Elderly patients with cervical spondylotic myelopathy show multiple cord compression on MRI, but SCEPs usually showed a single level of conduction block and 95% of focal conduction block at the C3/4 or C4/5 level.[18] Azuma *et al.*[19] reported that 78% of patients with cervical ossification of the posterior longitudinal ligament were determined by SCEPs to have a single site of conduction abnormalities and in about 70% the level was C3/4 or C4/5; however, they found multiple cord compression. These reports indicate multiple compression of the spinal cord on radiographic findings can include clinically silent compression. In our series, however, we evaluated only those patients with a single site of conduction abnormalities in the C3/4 and C4/5, as this has the most clinical relevance.

CONCLUSION

We have investigated 28 patients with CCM at the C3/4 and C4/5 intervertebral levels as determined by SCEPs. We suggest that small CMAPs amplitudes in the deltoid indicate a C3/4 level of myelopathy and in biceps at the C4/5 level. This study could help exclude clinically silent cord compression and determine the surgical procedure to the suitable level of concern.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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ORTHOPAEDIC SURGERY

Results of surgical treatment of cervical spondylotic myelopathy in patients aged 75 years or more: a comparative study of operative methods

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Abstract
Introduction The number of surgical procedures in elderly patients has been increasing as the population has grown older; recently, spine surgeons have been more likely to encounter elderly patients with cervical myelopathy in need of surgical treatment. There are many reports about surgical treatment of elderly patients with cervical spondylotic myelopathy (CSM); however, there are no studies about the proper selection of surgical methods and comparison of their results in CSM patients aged ≥75 years. The objective of this study was to review the results of operative methods in CSM patients aged ≥75 years.
Methods Forty-three consecutive cases with an average age of 79 years that underwent surgical treatment were included in this study. The neurological severity was assessed using the Japanese Orthopaedic Association score for cervical myelopathy (JOA). The JOA scores were evaluated before surgery and at final follow-up. There were 21 laminoplasty procedures (from C3 to C7), 13 selective laminoplasty procedures (one above and one below the affected intervertebral level), and nine anterior decompression and fusion procedures. A selective laminoplasty was performed in cases with general complications and was diagnosed as one intervertebral level both clinically and electrophysiologically. Surgical results were compared among the three treatment groups.
Results The average preoperative JOA score was 7.7 points and the average JOA recovery rate was 45 %. There were three cases of C5 palsy and one wound infection. Operative time and intraoperative bleeding in the selective laminoplasty group were significantly smaller than those in the other groups. There was no significant difference in the JOA recovery rates among the groups.
Conclusions Selective laminoplasty is less invasive and the surgical results in our study were almost good. It also has good short-term results. However, the indication for surgery has to be selected carefully in elderly CSM patients.

Keywords Cervical spondylotic myelopathy · Aged 75 years or more · Electrophysiology · Selective laminoplasty

Introduction

Spine surgeons have recently been more likely to encounter elderly patients in need of surgical treatment with aging of the population in developed countries. The elderly patients with cervical spondylotic myelopathy (CSM) have some degree of general complications. It is necessary to understand the clinical features of elderly CSM patients and to perform a minimally invasive decompression surgery in a safe and reliable way. Many studies have described cervical myelopathy in elderly patients [1–8]; however, there are few studies about the selection of surgical methods [9, 10] and no comparative study on the results of operative methods in elderly patients with CSM. The purpose of this study was to investigate surgical results corresponding to operative methods in CSM patients aged ≥75 years and to determine the optimal surgical method in elderly patients.

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Materials and methods

Subjects were selected from among 187 CSM patients who underwent surgery between January 2005 and August 2012. A total of 43 cases aged ≥75 years were included in this study (23 males and 20 females; average age 79 years). Other patients (e.g., ossification of posterior longitudinal ligament [OPLL] patients, patients with cervical disc herniation or a spinal tumor) were excluded because of the different mechanisms of the myelopathy involved. Of the subjects included, 21 underwent conventional laminoplasty (C3–7; hereafter, the LP group), 13 underwent selective laminoplasty (1 vertebra above and 1 below the responsible intervertebral level; hereafter, the SL group), and 9 underwent anterior decompression and fusion (hereafter, the AF group). The mean period of morbidity was 11 months (range: 1 month to 5 years), and 65 % of the subjects had a morbidity period of less than 6 months, indicating that rapid disease progression was common. The mean follow-up period was 2 years and 1 month (range: 6 months to 7 years and 2 months).

The study was approved by the Institutional Review Board of Yamaguchi University Hospital, and it adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from each patient.

Clinical assessment

For clinical assessment, we used the Japanese Orthopedic Association (JOA) scoring system for cervical myelopathy (Table 1). The JOA score quantifies neurological impairment by evaluating upper extremity function (4 points), lower extremity function (4 points), sensibility (6 points), and urinary bladder function (3 points). We evaluated differences in clinical data, surgical outcome, and postoperative complications among the groups. The surgical outcome was evaluated by the recovery ratio calculated using the preoperative and postoperative JOA scores [11].

Selection of a surgical method

The French window laminoplasty was performed on 34 patients. A selective laminoplasty of the arches of the two or more vertebrae surrounding the affected level was performed on subjects with preoperative complications (the Society of Anesthesiologists [ASA] Physical Status classification class 2: mild to moderate systemic disease or greater) who were diagnosed with CSM at a single intervertebral level or at two consecutive intervertebral levels based on preoperative neurological symptoms and imaging findings and when intraoperative electrophysiological level diagnosis corresponded to the former. Subjects showing improper alignment and marked localized instability were excluded [9]. The conventional C3–C7 laminoplasty was performed in patients with multilevel disease for whom the selective laminoplasty was contraindicated. Anterior decompression and fusion was performed on 9 patients. This procedure was performed on subjects with CSM at 1–2 intervertebral levels who showed instability at >5 mm of the anterior or posterior flexion as well as on subjects with marked anterior compression due to a large osteophyte.

Intraoperative spinal cord evoked potentials (SCEPs)

Intraoperative SCEPs were measured using a Nicolet Viking IV instrument (Nicole Biomedical, Madison, Wisconsin). We recorded 3 different SCEPs (Fig. 1a), measured following median nerve stimulation (MN-SCEPs), transcranial electric stimulation (Tc-SCEPs), and spinal cord stimulation (Sp-SCEPs). Electrodes (20–30 mA) were attached to the wrist for MN-SCEPs, needle electrodes (100 mA) were inserted 5 cm lateral and 2 cm forward of the Cz for Tc-SCEPs, and epidural catheter electrodes (10–15 mA) were attached to the thoracic vertebrae for Sp-SCEPs. Recordings were obtained from needle electrodes inserted in the ligamentum flavum between each vertebra, from C2/3 to C7/Th1 (Fig. 1b). In MN-SCEPs, the criterion for diagnosis was occurrence of positive potentials or a decrease of ≤30 % of the potentials in comparison to the C6/7 intervertebral level [12]. In Tc-SCEPs and Sp-SCEPs, the occurrence of positive potentials or a decrease in the potential of ≥50 % was considered abnormal [13, 14]. A diagnosis of the CSM level during a selective laminoplasty was made using the recordings from percutaneous electrodes that were inserted under imaging guidance, [9] as shown in Fig. 1.

Statistical analyses

We used Microsoft Excel Statistics for statistical analysis. The Mann–Whitney test was used to compare each pair of groups and the significance level was set at 5 %.

Results

The mean preoperative JOA score was 7.7 points (range 1.5–12.5), with serious cases being more common. The mean score at initial examination was 11.8 points (range 5–16.5), and the mean rate of improvement was 44.9 % (range 0–94). Five patients reported complete remission, 6 patients reported a favorable outcome, 26 patients reported an acceptable outcome, 2 patients reported an unsatisfactory outcome, and 4 patients reported worsening of their condition. When the groups were compared by surgical procedure, no significant differences in the ages at the

Table 1 Japanese Orthopaedic Association scoring system for cervical myelopathy

A	Motor function
I	Fingers
0	Unable to feed oneself with any tableware including chopsticks, spoon, or fork and/or unable to fasten buttons of any size
1	Can manage to feed oneself with a spoon and/or a fork but not with chopsticks
2	Either chopsticks-feeding or writing is possible but not practical, and/or large buttons can be fastened
3	Either chopstick-feeding or writing is clumsy but practical, and/or cuff buttons can be fastened
4	Normal
II	Shoulder and elbow (evaluated by MMT score of the deltoid or biceps muscles, whichever is weaker)
−2	MMT 2 or less
−1	MMT 3
0.5	MMT 4
0	MMT 5
III	Lower extremity
0	Unable to stand up and walk by any means
0.5	Able to stand up but unable to walk
1	Unable to walk without a cane or other support on a level surface
1.5	Able to walk without support but with a clumsy gait
2	Walks independently on a level surface but needs support on stairs
2.5	Able to walk independently when going upstairs, but needs support when going downstairs
3	Capable of fast but clumsy walking
4	Normal
B	Sensory function
I	Upper extremity
0	Complete loss of touch and pain sensation
0.5	Fifty percent or less normal sensation and/or severe pain or numbness
1	More than 60 % normal sensation and/or severe pain or numbness
1.5	Subjective numbness of slight degree without any objective sensory deficit
2	Normal
II	Trunk
0	Complete loss of touch and pain sensation
0.5	Fifty percent or less normal sensation and/or severe pain or numbness
1	More than 60 % normal sensation and/or moderate pain or numbness
1.5	Subjective numbness of slight degree without any objective sensory deficit
2	Normal
III	Lower extremity
0	Complete loss of touch and pain sensation
0.5	Fifty percent or less normal sensation and/or severe pain or numbness
1	More than 60 % normal sensation and/or moderate pain or numbness
1.5	Subjective numbness of slight degree without any objective sensory deficit
2	Normal
C	Bladder function
1	Urinary retention and/or incontinence
2	Sense of retention and/or dribbling and/or thin stream and/or incomplete continence
3	Urinary retardation and/or pollakiuria
4	Normal

Total for a healthy patient 17 points

MMT manual muscle test

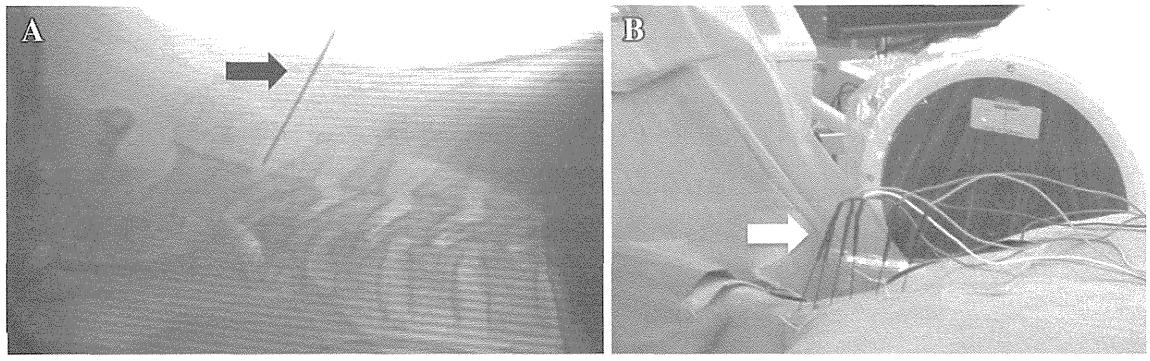

Fig. 1 The setup of the recording electrodes for a selective laminoplasty **a** a lateral view of the cervical spine on an image intensifier. Percutaneous insertion of a recording electrode (*black arrow*) into the ligamentum flavum at the C2/3 intervertebral level under imaging guidance. **b** An intraoperative photograph after the percutaneous insertion of the recording electrode. Percutaneous needle electrodes (*white arrows*) were inserted into each intervertebral space from C2/3 to C7/T1 under imaging guidance

time of surgery were observed [LP group: 79.3 ± 3 years (mean ± SD), SL group: 79.6 ± 3.2 years, and AF group: 77.4 ± 3.2 years)]. The preoperative JOA scores (LP group: 7.8 ± 2.4 points, SL group: 8.2 ± 2.5 points, and AF group: 6.6 ± 2.5 points) were lower in the AF group than in the SL group, although the difference was not statistically significant ($P = 0.085$). Duration of the procedure was 205 ± 40 min in the LP group, 110 ± 31 min in the SL group, and 203 ± 14 min in the AF group. The duration was significantly shorter in the SL group (SL vs. LP: $P = 0.000004$, SL vs. AF: $P = 0.0001$) than in the other groups. The intraoperative blood loss was 160 ± 123 g in the LP group, 57 ± 75 g in the SL group, and 127 ± 82 g in the AF group. The blood loss was significantly smaller in the SL group (SL vs. LP: $P = 0.003$, SL vs. AF: $P = 0.03$). The rate of improvement in the JOA score during final examination was 46.9 ± 26.7 % in the LP group, 43 ± 25.2 % in the SL group, and 43.1 ± 20.5 % in the AF group. No significant differences were observed among the groups (Table 2).

Diagnosis of injury level using intraoperative spinal cord-evoked potentials (SCEPs, $n = 33$) revealed that 26 subjects (79 %) had CSM of the superior cervical vertebrae (involving C3/4 and/or C4/5), 4 subjects (12 %) had CSM of the middle and lower cervical vertebrae (C4/5 and C5/6 or C5/6 or C6/7), and 3 subjects (9 %) had multilevel CSM involving 3 or more vertebrae. In addition, when limited to the spinal tract, CSM most commonly affected superior cervical intervertebral levels, with 28 patients (85 %) suffering from CSM affecting 1 or 2 superior cervical intervertebral levels (C3/4 or 4/5).

Four patients (9.3 %) developed postoperative complications. There were two cases of postoperative wound infection and two cases of postoperative C5 paralysis in the LP group (of these, one patient had both a wound infection and C5 paralysis), and one case of postoperative C5 paralysis in the AF group. No complications were observed in the SL group.

Table 2 Demographic data of three groups

Parameter	LP	SL	AF
Number	21	13	9
Age (years)	79.3 ± 3	79.6 ± 3.2	77.4 ± 3.2
Gender (men/women)	14/7	6/7	3/6
Symptom duration (months)	31 ± 40	22 ± 19	23 ± 26
Follow-up (months)	27 ± 22	21 ± 21	28 ± 14
Operative time (min)	205 ± 40	110 ± 31	203 ± 14
Intraoperative bleeding (g)	160 ± 123	57 ± 75	127 ± 82
JOA score (points)			
Preoperative	7.8 ± 2.4	8.2 ± 2.5	6.6 ± 2.5
Final follow-up	12 ± 2.9	11.9 ± 2.9	11.4 ± 1.2
Recovery ratio (%)	46.9 ± 26.7	43 ± 25.2	43.1 ± 20.5
Postoperative complication	3	0	1
Deep surgical site infection	2	0	0
Paraparesis (C5)	2	0	1

Values are presented as mean ± SD

JOA Japanese Orthopaedic Association scoring system for cervical myelopathy, *LP* laminoplasty from C3 to C7, *SL* selective laminoplasty, *AF* anterior decompression and fusion

Discussion

There are several reports in the literature regarding the pathology and postoperative outcomes in elderly patients with CSM; however, most reports involve nonelderly patients [1–8]. Very few reports describe the selection of a surgical procedure for elderly patients [9, 10], and reports that compare the outcomes of the respective procedures are few.

Tani et al. [13] used intraoperative SCEPs to investigate the pathology in elderly patients with CSM and observed a high rate of conduction disorders in patients with C3/4 and C4/5 injuries. In our study, we were able to diagnose the injury level intraoperatively using SCEPs in 33 patients. In