J. Spine Res. 6 : 1354-1362, 2015

Original Article

Excellent Papers of the 43rd Annual Meeting of the Japanese Society for Spine Surgery and Related Research

Evaluation of the Alarm Criteria for Transcranial Electrical Stimulation Muscle Evoked Potential in Spinal Deformity Surgery : Multi-institution Survey by the Spinal Cord Monitoring Committee of the Japanese Society for Spine Surgery and Related Research

Kei Yamada[*1], Yukihiro Matsuyama[*2], Sho Kobayashi[*2], Ken Nagahama[*3], Nobuaki Tadokoro[*4], Kanichiro Wada[*5], Akio Muramoto[*6], Hiroshi Iwasaki[*7], Tsukasa Kanchiku[*8], Shoji Seki[*9], Yujiro Hirao[*10], Atsuko Mizota[*1], Muneharu Ando[*11], Naoya Yamamoto[*12], Shigenori Kawabata[*13], Masahito Takahashi[*14], Zenya Ito[*6], Yasushi Fujiwara[*15], Kazunobu Kida[*4], Toshikazu Tani[*4], Ryo Ohta[*16], Takanori Saito[*17], Kazuhiko Satomi[*18], Kenichi Shinomiya[*19]

[*1]Department of Orthopaedics Surgery, Kurume University School of Medicine
[*2]Department of Orthopaedic Surgery, Hamamatsu University School of Medicine
[*3]Department of Orthopaedic Surgery, Hokkaido University Graduate School of Medicine
[*4]Department of Orthopaedic Surgery, Kochi Medical School
[*5]Department of Orthopaedic Surgery, Hirosaki University Graduate School of Medicine
[*6]Department of Orthopaedic Surgery, Nagoya University School of Medicine
[*7]Department of Orthopaedic Surgery, Wakayama Medical University
[*8]Department of Orthopaedic Surgery, Yamaguchi University Graduate School of Medicine
[*9]Department of Orthopaedic Surgery, University of Toyama
[*10]Department of Orthopaedic Surgery, The University of Tokyo Hospital
[*11]Department of Orthopaedic Surgery, Wakayama Rosai Hospital
[*12]Department of Orthopaedic Surgery, Tokyo Women's Medical University Yachiyo Medical Center
[*13]Department of Orthopaedic and Spinal Surgery, Graduate School of Medicine and Dental Science, Tokyo Medical and Dental University
[*14]Department of Orthopaedic Surgery, Kyorin University School of Medicine
[*15]Department of Orthopaedic Surgery, Hiroshima City Asa Citizens Hospital
[*16]Department of Orthopaedic Surgery, Hiroshima University
[*17]Department of Orthopaedic Surgery, Kansai Medical University Takii Hospital

Corresponding author : Kei Yamada MD, PhD, Department of Orthopaedics Surgery, Kurume University School of Medicine.
〔67 Asahi-machi Kurume, Fukuoka, 830-0011, Japan〕

Received August 20, 2014, accepted October 16, 2014

*[18]Department of Orthopaedic Surgery, Kugayama Hospital
*[19]Department of Orthopaedic Surgery, Yokohama City Red Cross Hospital

Abstract

Introduction：The alarm criteria for transcranial electrical stimulation motor evoked potentials (TES-MEP) have not yet been established. Accordingly the Spinal Cord Monitoring Committee of the Japanese Society for Spine Surgery and Related Research (JSSR) has suggested that a 70% amplitude loss in TES-MEP can be accepted. The aim of the present study is to evaluate the alarm criteria of TES-MEP during scoliosis surgery.

Methods：From April 2010 to March 2012, a total of 273 patients (male/female = 59/214) received spinal corrective surgery for scoliosis in twelve medical institutions, and were prospectively enrolled in this study. The alarm criteria was set at a 70% amplitude loss in TES-MEP. We investigated the correlation if any between wave change and any postoperative neurological deficit.

Results：27 of the subjects showed wave changes. Two of the 27 patients showed a wave change induced by derotation sustained transient postoperative motor loss. One patient presented complete wave loss after an abscission of the nerve roots showed persistent motor loss.

Conclusion：The 70% decrease in amplitude of TES-MEP was acceptable to prevent iatrogenic neurological deficit. Proper preventative measures after a warning of 70% amplitude loss could rescue neurological function from iatrogenic damage.

Key words：scoliosis, intraoperative monitoring, alarm criteria

Introduction

Iatrogenic spinal cord injury remains the most feared complication of spinal corrective surgery. The reported incidence of paralysis during spinal deformity corrective surgery is 1% to 2%[1)5)7)]. Transcranial electrical stimulation muscle evoked potential (TES-MEP) has been shown to be especially sensitive to spinal cord ischemia during spinal operations. However, an alarm criteria of TES-MEP has not yet been established[4)6)8)]. The Spinal Cord Monitoring Committee of the Japanese Society for Spine Surgery and Related Research (JSSR) has proposed a 70% amplitude loss in TES-MEP as an acceptable alarm criteria for TES-MEP in spinal surgery based on the result of a nationwide prospective study[3)]. Here, we presented a prospective study of 273 consecutive spinal deformity patients using TES-MEP during correction of deformity in order to determine whether the alarm criteria of ≥70% TES-MEP amplitude loss is reasonable for detecting and minimizing neurological complications during such surgeries.

Material and Method

The intraoperative monitoring records, operative narratives, and clinical findings were investigated for 273 consecutive patients who had undergone surgical correction of spinal deformity at twelve hospitals between April, 2010, and March, 2012. There were 59 male patients and 214 female patients ranging in age from five to eighty four years old (average, 36.3 years old) at the time of surgery. The clinical diagnoses of the patients were idiopathic scoliosis in 133 patients, adult degenerative kyphoscoliosis in 89 patients, symptomatic in 40 patients and congenital scoliosis in 11 patients. 270 patients underwent a posterior surgical approach. A combined anterior and posterior approach was performed in three patients. Important demographic and clinical data including age, gender, preoperative neurologic status and preoperative Cobb's angle were obtained from the patients clinical notes. The operative reports, anesthesia records, and spinal cord monitoring records were analyzed to determine temporal relationships between specific intraoperative events and consequent loss in the amplitude of TES-MEP in order to ascertain the effect of surgical interventions initiated to reverse those changes.

TES-MEP was recorded bilaterally from abductor pollicis brevis or abductor digital minimum in the upper extremities (control) and bilateral from, at minimum, the anterior tibialis muscles in the lower extremities. Other sites included the iliopsoas, quadriceps and gastrocnemius muscles depending on the complexity of the curve and the number of channels of neurophysiologic recording systems (Neuropack 8 or Neuromaster, Nihon Koden, Tokyo, Japan). These myogenic responses were elicited with use of the recording system or a commercially available transcranial electrical stimulator (Degitimer D185 ; Digitimer, Welwyn Garden City, United Kingdom) that delivered a brief (50 μsec), high-voltage (250～500 V) anodal pulse train (two to six pulses with a 2 to 3 msec interstimulus interval) between two corkscrew electrodes (or surface electrodes) inserted subcutaneously over motor cortex regions located 5cm lateral and 2cm anterior to Cz (International 10～20 System). An intraoperative "alert" or clinically relevant neurophysiologic change was defined as a persistent unilateral or bilateral loss of ≥70% of TES-MEP amplitude relative to a stable baseline. Besides TES-MEP, multimodal intraoperative monitoring was performed in eight hospitals.

Intravenous induction was carried out with propofol augmented with an opioid bolus.

General anesthesia was maintained, at all institutions, with pump-controlled intravenous infusions of propofol and remifentanil. A single bolus of non-depolarizing muscle relaxant (vecronium or atracrium) was given at induction to facilitate tracheal intubation and ventilation. No muscle relaxant was used following intubation so as not to compromise TES-MEP.

We measured the amplitude of TES-MEP before and after the invasive procedures including reduction or instrumentation. The amplitudes prior to the invasive procedures were regarded as control values. When a relevant neurophysiological change (≥70% loss of amplitude) occurred, several interventions were initiated. In our series, we did not determine an algorithm for intervention to reverse the neurological change. According to the alert by the monitoring technician or monitoring spine surgeon, each operator selected several interventions including termination of surgical procedure, reverse of precipitating procedures and administration of steroids, based on the neurophysiological situation and surgical procedure. The neurological state of each patient was evaluated after surgery. Any additional motor function deficit was considered to be a neurological impairment caused by spinal corrective surgery.

Statistical Analysis

An impending neurological injury was defined a priori as a relevant neurophysiological amplitude change, as detected by TES-MEP, necessitating some form of intervention. For the purpose of this study, calculation of test operating characteristics (sensitivity specificity, positive predictive value and negative predictive value) of TES-MEP was based on operational definitions of evolving and new-onset injury. A true-positive alert was defined as any relevant or complete loss of TES-MEP amplitude that was irreversible despite any intervention and was followed by postoperative neurologic deficit. A false-positive alert was defined as any case without postoperative newly developed neurologic deficit both in which the decrease in signal amplitude could not be reversed to baseline value regardless of intervention and in cases that reversed to baseline without any intervention. The result was classified as true-negative when no critical changes were demonstrated by neurophysiological monitoring and the patient awoke neurologically intact. Finally, the result was considered to be false-

Table 1 Demographics and clinical characteristics of wave change group and no wave change group.

	Wave change group (n = 27)	No wave change group (n = 246)	p value
age (mean, range)	27.7 (8～76)	37.2 (5～84)	0.03
gender			0.28
M/F	7/20	41/205	
IS (n)	14	119	
AKS (n)	5	84	
SS (n)	8	32	
CS (n)	0	11	
pre-Cobb's angle (mean, range)	54.9 (11～84)	53.0 (10～133)	0.36
correction rate (%) (mean, range)	66.8 (20～100)	71.7 (8～100)	0.29
Patient with post operative paralysis	3	0	0.0009

IS indicates idiopathic scoliosis. AKS indicates adult degenerative kyphoscoliosis. SS indicates symptomatic scoliosis. CS indicates congenital scoliosis.

negative when a patient awoke with a new neurological deficit even though the TES-MEP had not changed during the operation or a relevant signal change had resolved to baseline following intervention. A TES-MEP alert that normalized after intervensions in a patient who emerged with no new motor deficit was defined as a rescue case[3]. Significance between the wave change group and the no wave change group was determined using either the Mann-Whitney U test or Fisher exact test. P value less than 0.05 was considered significant. Informed consent was obtained from all patients. The study was conducted in accordance with the principle of the Declaration of Helsinki. The institutional ethics committee approved the study.

Result

The criteria for a relevant change in the amplitude of TES-MEP were met in twenty-seven (wave change group) of 273 patients (9.9%). There were 246 patients who did not show wave change (no wave change group) during the operation. The results of the intergroup comparison are summarized in **Table 1**. The age in Wave change group was younger than in the no wave change group. However there was no statistical difference in gender, preoperative Cobb's angle or correction rate. Relevant changes in amplitude were recognized in 14 out of 133 idiopathic scoliosis patients (10.5%), 8 out of 40 symptomatic scoliosis patients (20%) and 5 out of 89 adult degenerative kyphoscoliosis patients (5.6%). Two of 27 patients had an alert generated by hypotension and surgical exposure (**Figure 1**). The remaining 25 patients demonstrated signal amplitude changes attributed to specific surgical maneuvers. Twenty of the neuromonitoring alerts were associated with the application of corrective forces including derotation in 15, compression in 3, translation in 2 and distraction in one (**Figure 1**). In 6 cases, the alerts occurred during or following placement of pedicle screws. Another patient demonstrated more than 70% amplitude loss of TES-MEP after decompression (**Figure 1**).

Intervention and postoperative neurological deficit

In eight patients who presented a ≥70% amplitude

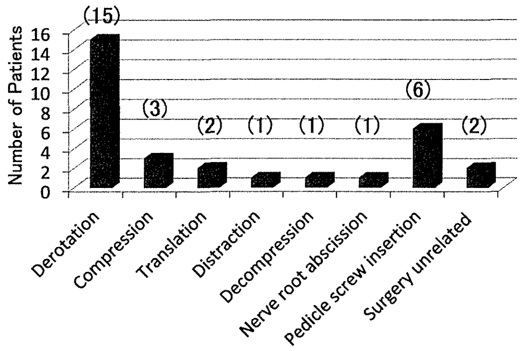

Figure 1 Surgical maneuvers leading to more than 70% amplitude loss of TES-MEP in 27 patients.
Parenthesis indicates the number of patients.

loss induced by derotation, the TES-MEP recovered after immediate intervention (**Table 2**). The intervention included decompression in 2, release of correction in 4, cease/release of correction/steroid administration in one and cessation of the surgical procedure in one (**Table 2**). In two patients who had a ≥70% amplitude loss induced by compression, the amplitude of TES-MEP improved after correction release (**Table 2**). These ten patients did not sustain postoperative newly developed neurological deficit. We considered these ten patients as rescue cases. There were 9 patients who showed significant amplitude loss of TES-MEP without any recovery of final TES-MEP in spite of any intervention excluding "observation" (**Table 2**). Two out of nine patients had postoperative transient neurologic deficit. One patient with adult

Table 2 Surgical maneuver, intervention, final TES-MEP recovery and post-operative neurological deficit.

Surgical procedure		Intervention		Final TES-MEP recovery		Post-ope ND	
DER	13	Decompression	5	(+)	2	(−)	2
				(−)	3	(+)	2
						(−)	1
		Correction release	4	(+)	4	(−)	4
		Compression/distraction	1	(−)	1	(−)	1
		Cessation/correction release/steroid	1	(+)	1	(−)	1
		Cessation	1	(+)	1	(−)	1
		Observation	1	(+)	1	(−)	1
DER/TR	1	Observation	1	(+)	1	(−)	1
DER/COMP/DIST/PS insertion	1	Observation	1	(−)	1	(−)	1
COMP	2	Correction release	2	(+)	2	(−)	2
TR	1	Observation	1	(+)	1	(−)	1
DECOMP	1	Observation	1	(+)	1	(−)	1
Nerve roots abscission	1	Decompression	1	(−)	1	(+)	1
PS insertion	5	Cessation	4	(−)	4	(−)	4
		Observation	1	(−)	1	(−)	1
Surgery unrelated	2	Observation	2	(+)	1	(−)	1
				(−)	1	(−)	1

DER indicates derotation. TR indicates translation. COMP indicates compression. DIST indicates distraction. PS indicates pedicle screw. ND indicates neurological deficit.
DECOMP indicates decompression. The numbers indicate the number of the patients.

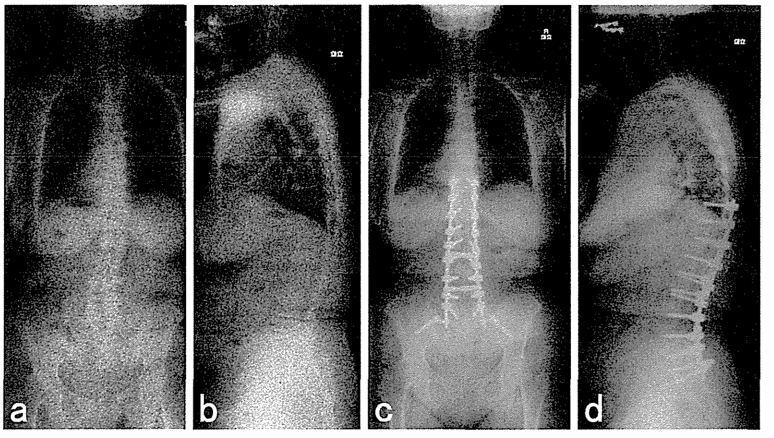

Figure 2 A true positive case of a 72-year-old female with adult degenerative kyphoscoliosis (Case 1).

(a) Anteroposteriol view of plain X-ray before surgery showed 20 degree coronal plane deformity.
(b) Lateral view of plain X-ray before surgery.
(c) She underwent corrective surgery. Post-operative Cobb's angle was 7 degrees.
(d) Lateral view of plain X-ray after the corrective surgery.

kyphoscoliosis and the other patient with symptomatic scoliosis showed wave changes induced by a derotation maneuver. They sustained postoperative motor loss despite preventative decompression. However, their motor function recovered in three months. Another patient with kyphoscoliosis induced by tuberculosis who underwent thoracic nerve roots abscission showed a complete loss of TES-MEP. Though the surgeon started intervention including decompression and vertebral column resection after the nerve roots abscission, TES-MEP did not recover. He awoke with newly-developed paraplegia which persisted one year after the operation. The other 6 patients did not have postoperative neurological deficits. When an alert was initiated in 8 patients, without any intervention (just observation), the amplitude recovered to baseline in 5 patients, whereas the remaining 3 patients did not have amplitude recovery. However, all 8 patients awake with no neurological deficit (**Table 2**). Those 14 patients were classified as a false positive group. Excluding the rescue cases, the sensitivity, - specificity, positive predictive value (PPV) and negative predictive value (NPV) of monitoring of TES-MEP for identification of motor loss were 100%, 94.5%, 17.6% and 100% respectively. There were no false-negative cases in our series.

Case presentation

Case 1. 72-year-old female with adult degenerative scoliosis underwent spine corrective surgery (**Figure 2**). During the derotation maneuver, the TES-MEP amplitude decreased more than 90%, which did not recover at the end of surgery (**Figure 3**). She had transient neurological deficit, which improved in three months.

Case 2. 55-year-old female with symptomatic scoliosis of acromegaly underwent spine corrective surgery (**Figure 4**). After the derotation maneuver, the TES-MEP amplitude decreased more than 90%, which did not recover finally (**Figure 5**). She had transient motor loss of bilateral quarliceps, which improved in three months.

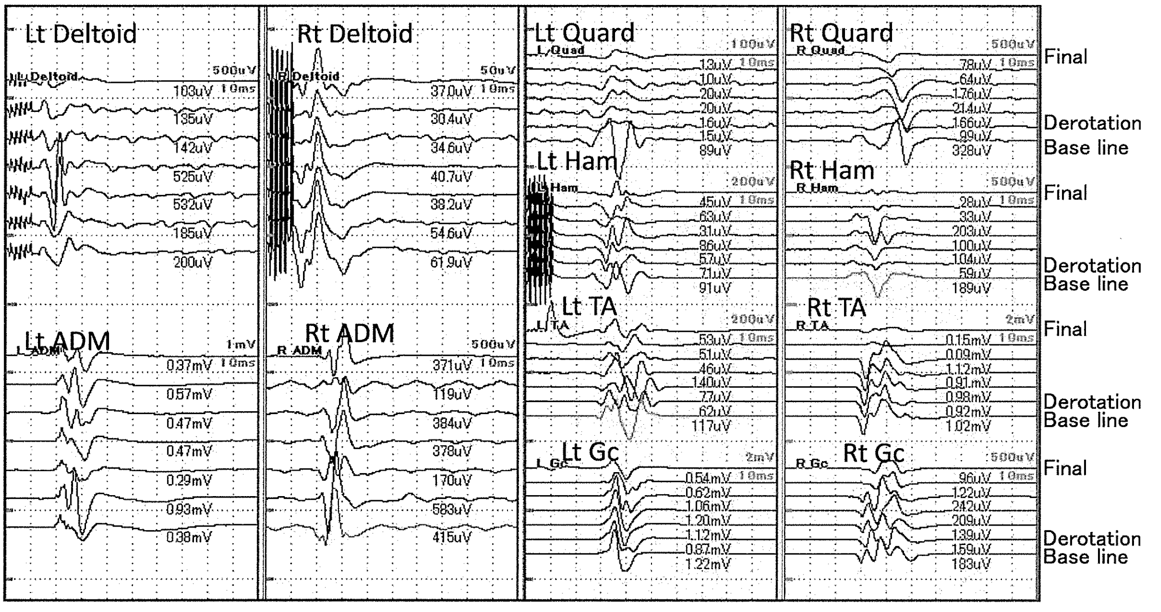

Figure 3 True positive TES-MEP of a 72-year-old female with adult degenerative kyphoscoliosis (Case. 1).
Note that TES-MEP amplitude of quardlicceps (Lt and Rt Quard), tibia anterior muscles (Lt and Rt TA), and hamstrings (Lt and Rt Ham) decreased more than 90% owing to derotation maneuver. TES-MEP amplitude of these muscles did not recover finally in spite of intervension (decompression). The motor loss improved in three months.

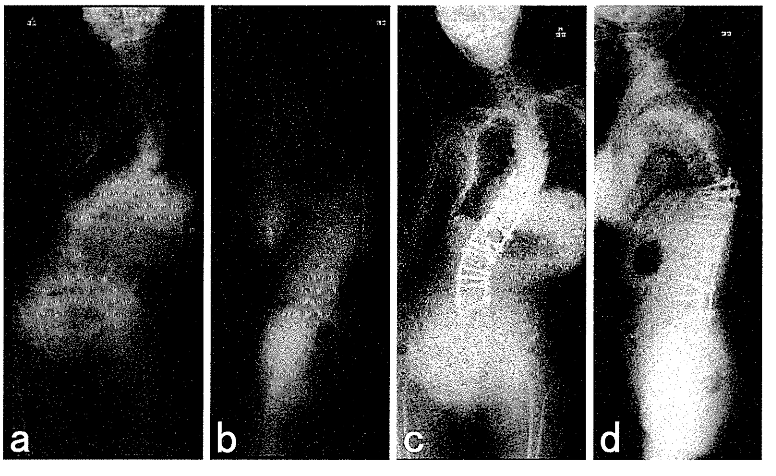

Figure 4 A true positive case of a 55-year-old female with symptomatic scoliosis of acromegaly (Case 2)
(a) Anteroposteriol view of plain X-ray before surgery showed Cobb's angle was 75 degree at thoracic spine and 71 degrees at lumbar spine level..
(b) Lateral view of plain X-ray before surgery showed kyphosis..
(c) She underwent corrective surgery. Post-operative Cobb's angle was 73 degrees at thoracic and 45 degrees at the lumbar spine..
(d) Lateral view of plain X-ray after the corrective surgery.

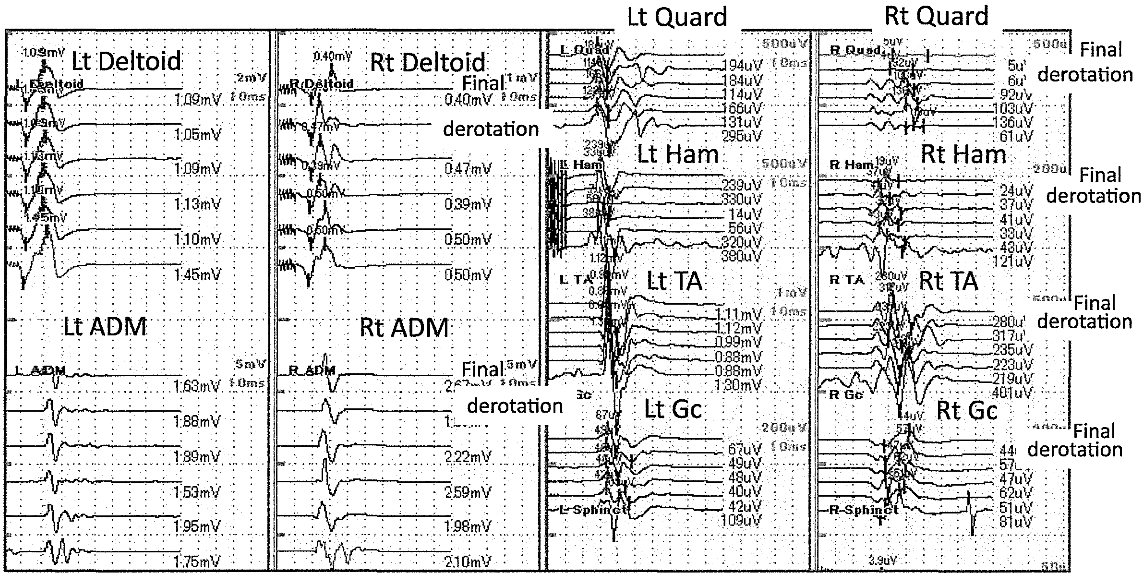

Figure 5 True positive TES-MEP of a 55-year-old female with symptomatic scoliosis (Case. 2).
Note that TES-MEP amplitude of right quardliceps (Rt Quard) and right hamstrings (Rt Ham) decreased more than 90% owing to derotation maneuver. TES-MEP amplitude of these muscles did not recover finally in spite of intervention (decompression). She woke up with motor loss of bilateral quardliceps. The motor loss improved in three months.

Discussion

Neurological deficit is one of the most severe risks of scoliosis surgical treatment and the assessment of its incidence varies from study to study[1)5)7)]. Timely detection of impending spinal cord damage is paramount. TES-MEP has been shown to be especially sensitive to spinal cord ischemia during spinal operations. So TES-MEP has become prevalent in spinal surgery. However, an alarm criteria for TES-MEP have not been established and varies widely between institutions. The current study reports the outcome of a large and heterogeneous population of scoliosis patients who underwent surgery for spinal deformity. We present data from a large, consecutive population of patients operated in twelve institutions under uniform analogous anesthesia and intraoperative monitoring conditions such as stimulation and alarm criteria (≥70% TES-MEP baseline amplitude loss). ≥70% amplitude loss was recognized in 27 patients (9.9%). In two patients, the amplitude changes were not related to surgical maneuvers. 15 patients showed a significant drop in the amplitude of lower limb TES-MEP during derotation, and 2 patients during compression. The reduction of corrective forces, cessation of the operation and decompression avoided postoperative neurologic sequelae in ten cases. During spine surgery, neurological complications may arise as the result of mechanical and/or vascular etiologies. The application of corrective forces on the spine during scoliosis surgery can cause stretching of the vascular supply making the spinal motor system vulnerable to ischemic insult.

Quraishi et al reported that two out of 102 adult spinal deformity patients awoke with postoperative paralysis using an alarm criteria of complete loss of TES-MEP during adult scoliosis surgery[6)]. Langeloo et al reported that 3 scoliosis patients showed persistent paralysis using an alarm criteria of ≥80% TES-MEP amplitude loss[4)]. In the current study, three out of 273 patients (1.1%) showed postoperative neurologic complications consisting of persistent paraplegia in one patient and transient paraparesis which recovered in 3 to 6 months in two patients. Reams reported 199 out of

19,360 scoliosis patients (1.0%) under 18 years old with postoperative newly developed neurological deficits according to the Scoliosis Research Society Database[7]. Divecha et al mentioned that 88 out of 4445 patients (2.0%) had postoperative neurological deficits from scoliosis surgery[1]. In the current study, the incidence of postoperative neurological deficit was not as high as in these reports, especially in regard to persistent paraplegia.

Using the alarm criteria of ≥70% TES-MEP amplitude loss, sensitivity and specificity were 100% and 94.6%, respectively. One patient with kyphoscoliosis induced by tuberculosis showed a loss of TES-MEP after a thoracic nerve roots abscission. The intervention including decompression and vertebral column resection after a nerve roots abscission did not improve the TES-MEP. He showed postoperative persistent paraplegia. The result of this case suggested that loss of TES-MEP amplitude might have indicated a vascular supply disorder of the spinal cord just after the nerve root abscission. In this case, there might not be any intervention available to rescue the spinal cord function even immediately after the TES-MEP alert. Moreover there was no false-negative case in our series. These results suggest that an alarm criteria ≥70% TES-MEP amplitude loss is a proper alert level for spinal deformity surgery.

The current study has several limitations. First, this is not a randomized study, so we could not make a comparison with other alarm criteria simultaneously. However, as such a randomized study would present ethical issues, we simply compared our result with other reports. Second, we did not investigate the alarm criteria with results of other monitoring modalities. We agree that multimodal intraoperative monitoring should be encouraged during spinal surgery[2)9)]. Third, we evaluated alarm criteria for scoliosis patients with various pathological conditions such as idiopathic scoliosis and adult spinal deformity. Further study should be considered to evaluate various alarm criteria specific to the clinical diagnoses of scoliosis.

Finally, TES-MEP is known to be the most sensitive monitoring modality in relation to other modalities such as somatosensory evoked potentials and transcranial electric stimulation spinal cord potentials. Even these days, as the alarm criteria has not been established, we should propose a proper alarm criteria of TES-MEP to start immediate intervention for the prevention of irreversible spinal cord damage. On that point, the current study confirmed the feasibility of an alarm criteria of 70%≥ TES-MEP amplitude loss during scoliosis surgery.

References

1) Divecha HM, Siddique I, Breakwell LM et al : Complication in spinal deformity surgery in United Kingdom : 5-year results of annual British Scoliosis Society National Audit of Morbidity and Mortality. Eur Spine J. 2014 ; 23 : S55-S66
2) Eggspuehler A, Sutter MA, Grob D et al : Multimodal intraoperative during surgery of spinal deformities in 217 patients. Eur Spine J. 2007 ; 16 : S188-S196
3) Kobayashi S, Matsuyama Y, Shinomiya K et al : A new alarm point of transcranial electrical stimulation motor evoked potentials for intraoperative spinal cord monitoring : a prospective multicenter study from the Spinal Cord Monitoring Working Group of the Japanese Society for Spine Surgery and Related Research. J Neurosurg Spine 2014 ; 20 : 102-107
4) Langeloo DD, Lelivelt A, Journee HL et al : Transcranial electrical motor-evoked potential monitoring during surgery for spinal deformity. A study of 145 patients. Spine. 2003 ; 28 : 1043-1050
5) Qiu Y, Wang S, Wang B et al : Incidence and risk factors of neurological deficits of surgical correction for scoliosis. Analysis of 1373 cases at one Chinese institution. Spine. 2008 ; 33 : 519-526
6) Quraishi NA, Lewis SJ, Kelleher MO et al : Intraoperative multimodality monitoring in adult spinal deformity. Spine. 2009 ; 34 : 1504-1512
7) Reames DL, Smith JS, Fu KG et al : Complication in the surgical treatment of 19,360 cases of pediatric scoliosis. A review of the Scoliosis Research Society Morbidity and Mortality Databease. Spine. 2011 ; 36 : 1484-1491
8) Schwartz DM, Auerbach JD, Dormans JP et al : Neurophysiological detection of impending spinal cord injury during scoliosis surgery. J Bone Joint Surg Am. 2007 ; 89 : 2440-2449
9) Sutter M, Eppspuehler A, Muller A et al : Multimodal intraoperative monitoring : an overview and proposal of methodology based on 1,017 cases. Eur Spine J. 2007 ; 16 : S153-S161

What Is the Best Multimodality Combination for Intraoperative Spinal Cord Monitoring of Motor Function? A Multicenter Study by the Monitoring Committee of the Japanese Society for Spine Surgery and Related Research

Zenya Ito[1] Yukihiro Matsuyama[2] Muneharu Ando[3] Shigenori Kawabata[4] Tsukasa Kanchiku[5] Kazunobu Kida[6] Yasushi Fujiwara[7] Kei Yamada[8] Naoya Yamamoto[9] Sho Kobayashi[2] Takanori Saito[10] Kanichiro Wada[11] Kazuhiko Satomi[12] Kenichi Shinomiya[13] Toshikazu Tani[6]

[1]Nagoya University, Nagoya, Aichi Prefecture, Japan
[2]Hamamatsu Medical University, Hamamatsu, Shizuoka, Japan
[3]Wakayama Rosai Hospital, Wakayama, Japan
[4]Tokyo Medical and Dental University, Tokyo, Japan
[5]Yamaguchi University, Yamaguchi, Japan
[6]Kubokawa Hospital, Shimanto, Kochi, Japan
[7]Asa Citizens Hospital, Hiroshima, Japan
[8]Kurume University, Kurume, Japan
[9]Tokyo Women's Medical University, Tokyo, Japan
[10]Kansai Medical University, Moriguchi, Osaka, Japan
[11]Hirosaki University, Hirosaki, Aomori, Japan
[12]Kugayama Hospital, Tokyo, Japan
[13]Yokohama City Minato Red Cross Hospital, Yokohama, Kanagawa, Japan

Address for correspondence Zenya Ito, MD, Department of Orthopedic Surgery, Nagoya University School of Medicine, 65 Tsurumai Shyowa-ward, Aichi 466-8550, Japan (e-mail: z.ito@nifty.com).

Global Spine J

Abstract

Study Design Surgeon survey.

Objective To analyze multimodal intraoperative monitoring (MIOM) for different combinations of methods based on the collected data and determine the best combination.

Methods A questionnaire was sent to 72 training institutions to analyze and compile data about monitoring that had been conducted during the preceding 5 years to obtain data on the following: (1) types of monitoring; (2) names and number of diseases; (3) conditions of anesthesia; (4) condition of stimulation, the monitored muscle and its number; (5) complications; and (6) preoperative and postoperative manual muscle testing, presence of dysesthesia, and the duration of postoperative motor deficit. Sensitivity and specificity, false-positive rates, and false-negative rates were examined for each type of monitoring, along with the relationship between each type of monitoring and the period of postoperative motor deficit.

Results Comparison of the various combinations showed transcranial electrical stimulation motor evoked potential (TcMEP) + cord evoked potential after stimulation to the brain (Br-SCEP) combination had the highest sensitivity (90%). The TcMEP +

Keywords
- monitoring
- multimodality
- sensitivity
- specificity

received September 8, 2014
accepted after revision June 22, 2015

DOI http://dx.doi.org/10.1055/s-0035-1559582.
ISSN 2192-5682.

somatosensory evoked potential (SSEP) and TcMEP + spinal cord evoked potential after stimulation to the spinal cord (Sp-SCEP) combinations each had a sensitivity of 80%, exhibiting little difference between their sensitivity and that obtained when TcMEP alone was used. Meanwhile, the sensitivity was as low as 50% with Br-SCEP + Sp-SCEP (i.e., the cases where TcMEP was not included).

Conclusions The best multimodality combination for intraoperative spinal cord monitoring is TcMEP + Br-SCEP, which had the highest sensitivity (90%), the lowest false-positive rate (6.1%), and the lowest false-negative rate (0.2%).

Introduction

Somatosensory evoked potential (SSEP) has been used to monitor spinal surgery since the 1980s,[1–5] and cord evoked potential after stimulation to the brain (Br-SCEP, D-wave) has also been used for motor pathway monitoring since the 1990s.[6–11] Other monitoring techniques followed, including free-running electromyography,[12,13] spinal cord evoked potential after stimulation to the spinal cord (Sp-SCEP), spinal cord evoked potential after stimulation to the peripheral nerve (Pn-SCEP), and transcranial electrical stimulation motor evoked potential (TcMEP).[14–18] In particular, TcMEP is regarded as the most sensitive monitoring.[10] Although it has been reported that TcMEP shows accurate real-time invasiveness of surgery with nearly 100% sensitivity and specificity, there are occasional reports that TcMEP, being highly sensitive, produces a relative high frequency of false-positives, thus hindering the surgery.[19–21] Accordingly, the importance of multimodality monitoring rather than single-modality approaches has been pointed out in numerous reports. Upon studying 1,017 cases of multimodal intraoperative monitoring (MIOM), Sutter et al reported the usefulness of MIOM, citing 89% of sensitivity and 99% of specificity,[22] and Sala et al reported the usefulness of the combination of TcMEP and D-wave for intramedullary spinal cord tumor.[9] Previous reports, however, used different modality combinations for MIOM. Furthermore, in no previous reports has any comparison been made among different combinations in terms of sensitivity or specificity. We at the Monitoring Committee of the Japanese Society for Spine Surgery and Related Research conducted a nationwide multicenter study in 2007 and collected data from 7,158 cases of monitoring performed at numerous institutions during the preceding 5 years.[23] The objective of this study is to evaluate the usefulness of various combinations of monitoring techniques to detect motor deficits after surgery.

Materials and Methods

Subjects

From 2007 to 2010, the Monitoring Committee of the Japanese Society for Spine Surgery and Related Research conducted a nationwide multicenter study to determine the manner in which intraoperative spinal cord monitoring was conducted. A questionnaire was sent to 72 training institutions to analyze and compile data about cases of monitoring that had been conducted during the preceding 5 years. The questionnaire asked about: (1) the types of monitoring; (2) the names and number of disease; (3) the conditions of anesthesia; (4) the condition of stimulation, the monitored muscle and its number; (5) any complications; (6) the preoperative and postoperative manual muscle testing (MMT), presence of dysesthesia, the duration of postoperative motor deficit. The MMT is graded as follows: grade 0, no perceptible muscle contraction; grade 1, muscle contraction palpable, but no motion; grade 2, motion of the part only with gravity reduced; grade 3, the muscle can hold the part in the test position against gravity alone; grade 4, the patient can move the part through the full active range of motion against "some" resistance; grade 5, the patient can move the part through the full active range of motion against "full" resistance. MMT was performed at final follow-up (average 7.8 months) after surgery by a third party.[20] A total of 7,158 cases of monitoring were compiled. Appropriate Institutional Review Board approval was obtained.

Criteria for Selecting Cases

The prerequisites for inclusion in the baseline data were as follows: (1) cases in which monitoring was conducted under the stimulation condition shown in ►**Table 1**; (2) cases in which monitoring was conducted under the recording condition shown in ►**Table 1**; (3) cases recorded at institutions where loss of amplitude for TcMEP and amplitude loss of 50% or more or latency delay of 10% or more for Br-SCEP, Sp-SCEP, and SSEP were used as the alarm points. When any of the waveforms changed during the surgery, we ordered the anesthetist to raise the systolic blood pressure blood pressure or reverse hypotensive anesthesia and warm the core temperature. If the waveform still did not recover, such cases were considered positive as regards to the waveform change, and the surgeon was alerted to suspend the surgery. It was regarded as true-positive if postoperative paralysis was recognized, and it was regarded as false-positive if postoperative paralysis was not recognized. The anesthesia management that allows intraoperative monitoring particularly of TcMEP consists of a constant infusion of propofol (usually in a dose of ~100 to 150 μg/kg/min) and fentanyl (usually around 1 μg/kg/h). Short-acting muscle relaxants are given during intubation but not thereafter to allow continuous TcMEP monitoring.[10] Halogenated anesthetics should not be used.

Table 1 Monitoring condition of stimulation and recording

Imaging method	Stimulation	Stimulus	ISI (ms)	Intensity (mA)	Duration (ms)	Recording	Electrodes	Filters (kHz)	Sweep (ms/D)	Averaging
TcMEP	Scalp	Repeated train of 5 (2–6) stimuli	2.5 (2–3)	100 (50–200)	0.5 (0.2–0.8)	Muscles of interest synchronous	2 surface electrodes/muscle	0.05–3	10	1
Br-SCEP	Scalp	Repeated single stimulus	–	100 (50–200)	0.5	Spinal cord epidural or subarachnoid	Bipolar spinal electrode	0.5–3	2	4–10
Sp-SCEP	Spinal cord	Repeated single stimulus	–	0.5–15	0.2	Spinal cord epidural	Epidural or subarachnoid	2–3	1	50–200
SSEP	Nerve	Repeated single stimulus	–	10–50	0.2	Scalp	C3′–C4′; C4′–C3′; Cz-Fz	0.05–3	10	100–1,000

Abbreviations: Br-SCEP, cord evoked potential after stimulation to the brain; D, division; ISI, interstimulus interval; Sp-SCEP, spinal cord evoked potential after stimulation to the spinal cord; SSEP, somatosensory evoked potential; TcMEP, transcranial electrical stimulation motor evoked potential.

Of the 7,158 cases, 3,028 met these criteria. In particular, 1,396 cases of single-modality monitoring (SIOM; 17 institutions) and 1,632 cases of MIOM (13 institutions) were selected as the subjects of this study (►**Fig. 1**).

►**Tables 2** and **3** show the breakdown of the diseases between SIOM and MIOM groups.

Examined Items

The sensitivity and specificity (separately for SIOM and MIOM), the false-positive rate, the false-negative rate of each type of monitoring, and the relationship between each type of monitoring and the period of postoperative motor deficit were examined. Statistical analysis was performed using the paired *t* test.

Results

Fifty-nine cases (1.9%) of postoperative motor deficit were identified with 46 true-positive cases and 13 false-negative cases (►**Fig. 2**). There were 191 false-positive cases with an overall sensitivity of 78% and an overall specificity of 94%.

Sensitivity and Specificity in the Single-Modality Monitoring Group

The SIOM group included 22 cases of postoperative motor deficit, in which 17/884 cases (1.9%) occurred with TcMEP, 3/140 cases (2.1%) with Sp-SCEP, and 2/372 cases (0.5%) with SSEP. The overall sensitivity and specificity in the SIOM group were 72 and 95%, respectively, with a false-positive rate of 5%. Review of each type of monitoring revealed that TcMEP had a significantly higher sensitivity (82%) than Sp-SCEP. The sensitivity was significantly lower in the cases where only Sp-SCEP or SSEP was conducted (SSEP: 50%, Sp-SCEP: 33%; see ►**Fig. 3** and ►**Table 4**).

Sensitivity and Specificity in the Multimodality Monitoring Group

The MIOM group included 37 cases of postoperative paralysis, in which 10/540 cases (1.9%) occurred with TcMEP + Br-SCEP, 19/718 cases (2.8%) with TcMEP + SSEP, 5/247 cases (2.0%) with TcMEP + Sp-SCEP, and 2/127 cases (2.0%) with Br-SCEP + Sp-SCEP. The overall sensitivity and specificity in the MIOM group were 81 and 92%, respectively, with the sensitivity higher than in SIOM group, but the difference was not statistically significant. The comparison of the various combinations showed the TcMEP + Br-SCEP combination to have the highest sensitivity of 90%. The TcMEP + SSEP and TcMEP + Sp-SCEP combinations each had a sensitivity of 80%, exhibiting little difference between their sensitivity and that obtained when TcMEP alone was used. Meanwhile, the sensitivity was as low as 50% among Br-SCEP + Sp-SCEP cases (i.e., the cases where TcMEP was not included; see ►**Fig. 4** and ►**Table 4**).

False-Positive and False-Negative Rates in Multimodality Monitoring Group

The false-positive and false-negative rate in the overall MIOM group was 7.4 and 0.4%, respectively. These rates were

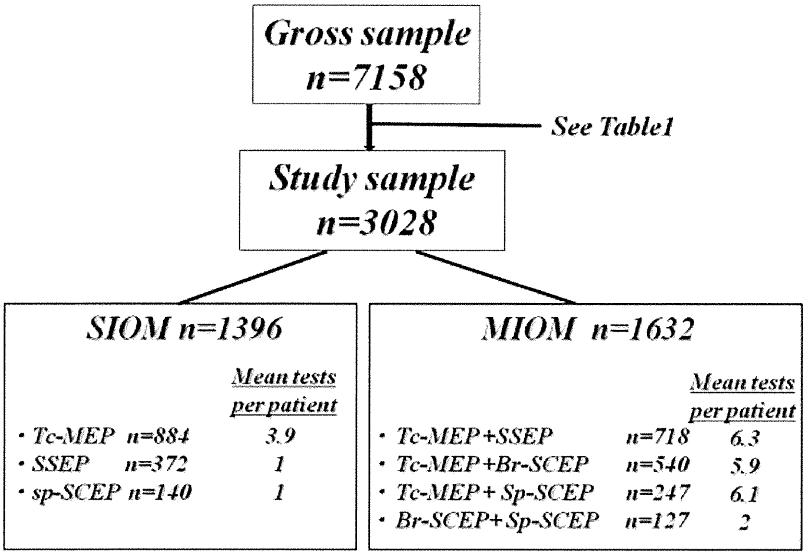

Fig. 1 Flowchart of the subjects of this study showing mean tests per patient and mean recording numbers. Abbreviations: Br-SCEP, cord evoked potential after stimulation to the brain; MIOM, multimodal intraoperative monitoring; SIOM, single-modality monitoring; Sp-SCEP, spinal cord evoked potential after stimulation to the spinal cord; SSEP, somatosensory evoked potential; Tc-MEP, transcranial electrical stimulation motor evoked potential.

significantly higher in the cases where TcMEP was included ($p < 0.005$). These rates were significantly lower in the cases where Br-SCEP was included ($p < 0.005$). Although the difference in the false-negative rates among the combinations was not statistically significant, the TcMEP + Br-SCEP combination registered the lowest rate (0.2%; see ►**Figs. 5, 6** and ►**Table 4**).

Relationship between Duration of Postoperative Motor Deficit and Monitoring

Of the 59 cases involving postoperative motor deficit, the duration was less than 3 months in 35 cases (59%) and 3 months or more in 24 cases (41%). The postoperative motor deficit continued for 3 months or longer in 10 (45%) of the 22 cases in SIOM group and 14 (38%) of the 37 cases in MIOM group, but the difference between the two groups was not statistically significant. Comparison of the various combinations revealed no significance, either.

Discussion

Among spinal surgeries, intramedullary tumor resection,[2,24] ossification of posterior longitudinal ligaments (OPLL) decompression, and scoliosis surgery in particular may have to be performed in critical situations.[25–28] Although numerous studies reported the advantages of MIOM, they failed to

Table 2 Breakdown in single-modality intraoperative monitoring group

Diagnosis	Total	TcMEP	SSEP	Sp-SCEP
Scoliosis	309	204	84	21
Spinal tumor (epidural, subdural, intramedullary)	428	321	87	20
Cervical spinal myelopathy	250	109	90	51
OPLL (cervical, thoracic)	145	65	55	25
Vertebral tumor (primary, metastasis)	25	7	8	10
Trauma	12	8	3	1
Lumber spinal stenosis	7	2	5	0
Disk herniation	22	12	10	0
Miscellaneous	198	156	30	12
Total	1396	884	372	140

Abbreviations: Br-SCEP, cord evoked potential after stimulation to the brain; OPLL, ossification of posterior longitudinal ligaments; Sp-SCEP, spinal cord evoked potential after stimulation to the spinal cord; SSEP, somatosensory evoked potential; Tc-MEP, transcranial electrical stimulation motor evoked potential.

Table 3 Breakdown in multimodality intraoperative monitoring group

Diagnosis	Total	TcMEP+ SSEP	TcMEP+ Br-SCEP	TcMEP+ Sp-SCEP	Br-SCEP+ Sp-SCEP
Scoliosis	347	149	110	62	26
Spinal tumor (epidural, subdural, intramedullary)	262	167	51	24	20
Cervical spinal myelopathy	226	100	68	35	23
OPLL (cervical, thoracic)	152	76	20	31	25
Vertebral tumor (primary, metastasis)	109	58	26	15	10
Trauma	50	14	21	14	1
Lumber spinal stenosis	11	11	0	0	0
Disk herniation	18	18	0	0	0
Miscellaneous	451	125	244	66	22
Total	1632	718	540	247	127

Abbreviations: Br-SCEP, cord evoked potential after stimulation to the brain; OPLL, ossification of posterior longitudinal ligaments; Sp-SCEP, spinal cord evoked potential after stimulation to the spinal cord; SSEP, somatosensory evoked potential; TcMEP, transcranial electrical stimulation motor evoked potential.

examine the combinations of MIOM methods. Furthermore, no comparisons have been made among the different combinations in terms of sensitivity or specificity.

Although recognizing no significance, this study does show MIOM has a higher sensitivity (81%) than SIOM (72%), thus confirming the greater usefulness of MIOM. Of the MIOM group, the combinations that included TcMEP had particularly higher sensitivities (80% or more) than the Br-SCEP + Sp-SCEP combination (50%), suggesting that TcMEP is essential for spinal monitoring. The group including Br-SCEP had significantly lower false-positive and false-negative rates, indicating the necessity of Br-SCEP for accurate monitoring. In view of the above, it may be concluded that the TcMEP + Br-SCEP combination is the most reliable monitoring with the highest sensitivity of 90% in motor function.

MacDonald et al reported the sensitivity and specificity of TcMEP + SSEP combination as 70% and 93%, respectively,[29] whereas Sutter et al used 11 types of monitoring and reported

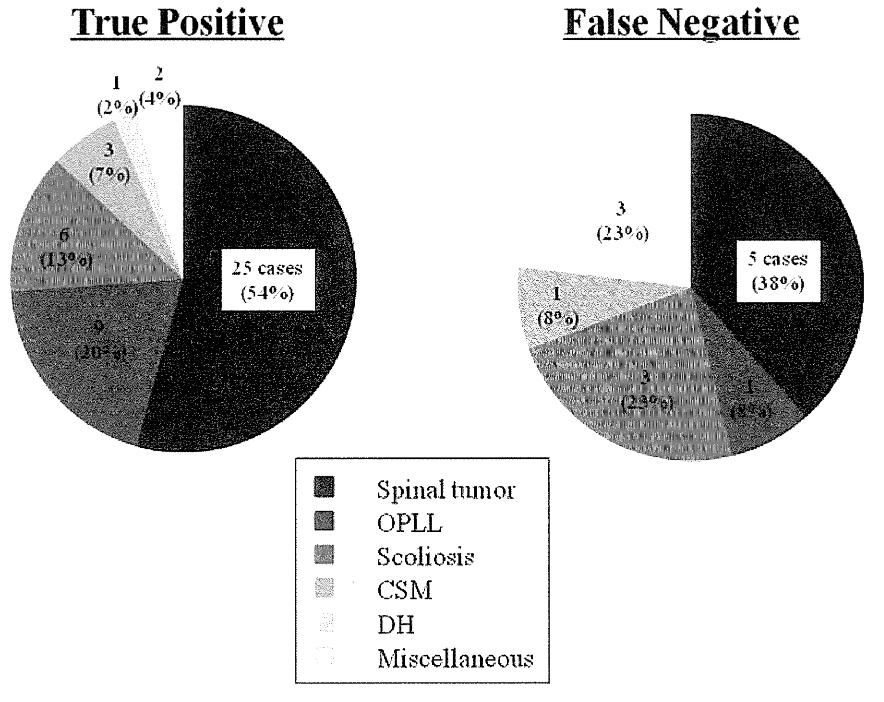

Fig. 2 Breakdown and number for motor deficit cases. Abbreviations: CSM, cervical spondylotic myelopathy; DH, disk herniation; OPLL, ossification of posterior longitudinal ligaments.

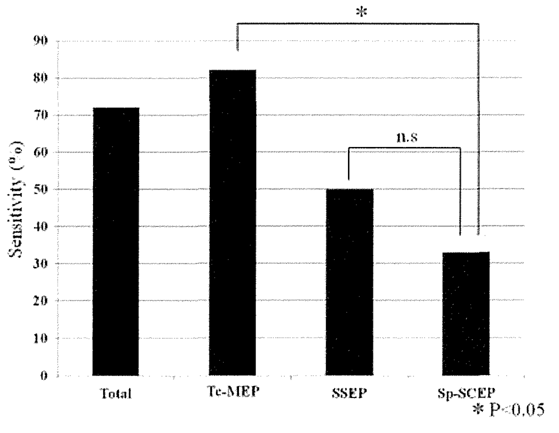

Fig. 3 Sensitivity rate for single-modality monitoring group. Abbreviations: n.s., not significant; Sp-SCEP, spinal cord evoked potential after stimulation to the spinal cord; SSEP, somatosensory evoked potential; Tc-MEP, transcranial electrical stimulation motor evoked potential.

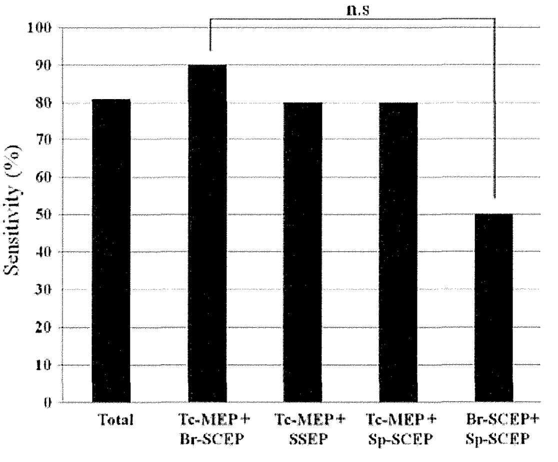

Fig. 4 Sensitivity rate for multimodal intraoperative monitoring group. Abbreviations: Br-SCEP, cord evoked potential after stimulation to the brain; n.s., not significant; Sp-SCEP, spinal cord evoked potential after stimulation to the spinal cord; SSEP, somatosensory evoked potential; Tc-MEP, transcranial electrical stimulation motor evoked potential.

Table 4 Sensitivity and specificity in the SIOM and MIOM groups

	Motor deficit +	Motor deficit −	PPV, NPV, false-positive rate
SIOM group			
TcMEP			
Waveform change +	14	56	PPV 20%
Waveform change −	3	811	NPV 99%
Sensitivity, specificity	Sensitivity 82%	Specificity 94%	False-positive 6.4%
SSEP			
Waveform change +	1	10	PPV 10%
Waveform change −	1	350	NPV 99%
Sensitivity, specificity	Sensitivity 50%	Specificity 97%	False-positive 2.8%
Sp-SCEP			
Waveform change +	1	4	PPV 20%
Waveform change −	2	133	NPV 98%
Sensitivity, specificity	Sensitivity 33%	Specificity 97%	False-positive 2.9%
MIOM group			
TcMEP + Br-SCEP			
Waveform change +	9	33	PPV 21%
Waveform change −	1	497	NPV 99%
Sensitivity, specificity	Sensitivity 90%	Specificity 94%	False-positive 6.1%
TcMEP + SSEP			
Waveform change +	16	66	PPV 20%
Waveform change −	4	632	NPV 99%
Sensitivity, specificity	Sensitivity 80%	Specificity 91%	False-positive 9.2%

Table 4 (*Continued*)

	Motor deficit +	Motor deficit −	PPV, NPV, false-positive rate
TcMEP + Sp-SCEP			
Waveform change +	4	27	PPV 13%
Waveform change −	1	215	NPV 99%
Sensitivity, specificity	Sensitivity 80%	Specificity 89%	False-positive 10.9%
Br-SCEP + Sp-SCEP			
Waveform change +	1	1	PPV 50%
Waveform change −	1	124	NPV 99%
Sensitivity, specificity	Sensitivity 50%	Specificity 99%	False-positive 0.8%

Abbreviations: Br-SCEP, cord evoked potential after stimulation to the brain; MIOM, multimodal intraoperative monitoring; NPV, negative predictive value; PPV, positive predictive value; Sp-SCEP, spinal cord evoked potential after stimulation to the spinal cord; SIOM, single-modal intraoperative monitoring; SSEP, somatosensory evoked potential; TcMEP, transcranial electrical stimulation motor evoked potential.

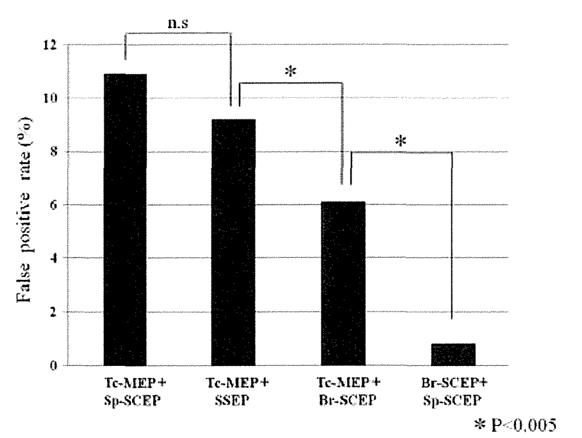

Fig. 5 False-positive rate for multimodal intraoperative monitoring group. Abbreviations: Br-SCEP, cord evoked potential after stimulation to the brain; n.s., not significant; Sp-SCEP, spinal cord evoked potential after stimulation to the spinal cord; SSEP, somatosensory evoked potential; TcMEP, transcranial electrical stimulation motor evoked potential.

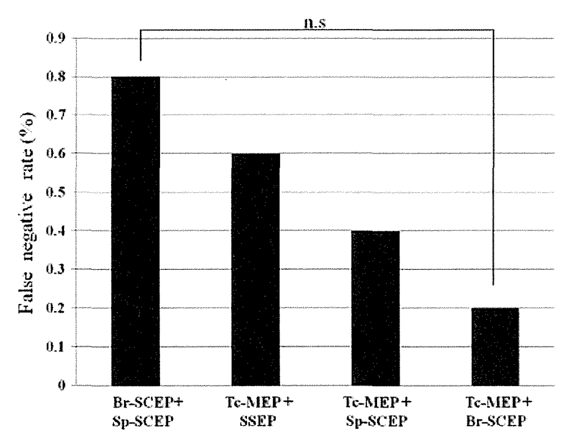

Fig. 6 False-negative rate for multimodal intraoperative monitoring group. Abbreviations: Br-SCEP, cord evoked potential after stimulation to the brain; n.s., not significant; Sp-SCEP, spinal cord evoked potential after stimulation to the spinal cord; SSEP, somatosensory evoked potential; TcMEP, transcranial electrical stimulation motor evoked potential.

the overall sensitivity and specificity as 89 and 99%, respectively.[22] Eggspuehler et al used nine types of monitoring for spinal deformity and reported the sensitivity and specificity as 92.3 and 98.5%, respectively.[30] Although overall sensitivity and specificity are reported, no study has reported the rates for the different combinations. In addition, although Sutter et al reported false-positive and false-negative rates of 0.8 and 0.8%, respectively,[22] our false-negative rate was extremely high (7.2%). Presumably, this difference is because Sutter et al normally used at least four modalities and we monitored with three modalities at most. A large number of different surgical procedures were compiled, so we need to study rates in each procedure. However, this report is the first to investigate the combination of MIOM methods for intraoperative spinal cord monitoring, and accordingly it is important as a preliminary study.

One limitation of this study is that after the cases were sorted into different combinations, there were not enough cases of motor deficit in each combination to compare in sensitivity and specificity. Therefore, a study with more cases is needed. Second, this study used no more than two modalities, which was fewer than previous reports. Considering the great deal of labor required, it will be difficult to use a larger number of modalities. Still, studies with more combinations need to be conducted if motor deficits are to be prevented.

Finally, a large number of different surgical procedures were compiled, and each procedure needs to be studied.

Conclusion

The best multimodality combination for intraoperative spinal cord monitoring is TcMEP + Br-SCEP, which had the highest sensitivity (90%), the lowest false-positive rate (6.1%), and the lowest false-negative rate (0.2%).

Disclosures
Zenya Ito, none
Yukihiro Matsuyama, none
Muneharu Ando, none
Shigenori Kawabata, none
Tsukasa Kanchiku, none
Kazunobu Kida, none
Yasushi Fujiwara, none
Kei Yamada, none
Naoya Yamamoto, none
Sho Kobayashi, none
Takanori Saito, none
Kanichiro Wada, none
Kazuhiko Satomi, none
Kenichi Shinomiya, none
Toshikazu Tani, none

References

1 Ben-David B, Haller G, Taylor P. Anterior spinal fusion complicated by paraplegia. A case report of a false-negative somatosensory-evoked potential. Spine (Phila Pa 1976) 1987;12(6):536–539
2 Ginsburg HH, Shetter AG, Raudzens PA. Postoperative paraplegia with preserved intraoperative somatosensory evoked potentials. Case report. J Neurosurg 1985;63(2):296–300
3 Lesser RP, Raudzens P, Lüders H, et al. Postoperative neurological deficits may occur despite unchanged intraoperative somatosensory evoked potentials. Ann Neurol 1986;19(1):22–25
4 Zileli M, Coşkun E, Ozdamar N, et al. Surgery of intramedullary spinal cord tumors. Eur Spine J 1996;5(4):243–250
5 Zornow MH, Grafe MR, Tybor C, Swenson MR. Preservation of evoked potentials in a case of anterior spinal artery syndrome. Electroencephalogr Clin Neurophysiol 1990;77(2):137–139
6 Kothbauer KF, Deletis V, Epstein FJ. Motor-evoked potential monitoring for intramedullary spinal cord tumor surgery: correlation of clinical and neurophysiological data in a series of 100 consecutive procedures. Neurosurg Focus 1998;4(5):e1
7 Kothbauer K, Deletis V, Epstein FJ. Intraoperative spinal cord monitoring for intramedullary surgery: an essential adjunct. Pediatr Neurosurg 1997;26(5):247–254
8 Fujiki M, Furukawa Y, Kamida T, et al. Intraoperative corticomuscular motor evoked potentials for evaluation of motor function: a comparison with corticospinal D and I waves. J Neurosurg 2006;104(1):85–92
9 Sala F, Palandri G, Basso E, et al. Motor evoked potential monitoring improves outcome after surgery for intramedullary spinal cord tumors: a historical control study. Neurosurgery 2006;58(6):1129–1143, discussion 1129–1143
10 Sala F, Bricolo A, Faccioli F, Lanteri P, Gerosa M. Surgery for intramedullary spinal cord tumors: the role of intraoperative (neurophysiological) monitoring. Eur Spine J 2007;16(Suppl 2):S130–S139
11 Ulkatan S, Neuwirth M, Bitan F, Minardi C, Kokoszka A, Deletis V. Monitoring of scoliosis surgery with epidurally recorded motor evoked potentials (D wave) revealed false results. Clin Neurophysiol 2006;117(9):2093–2101
12 Jimenez JC, Sani S, Braverman B, Deutsch H, Ratliff JK. Palsies of the fifth cervical nerve root after cervical decompression: prevention using continuous intraoperative electromyography monitoring. J Neurosurg Spine 2005;3(2):92–97
13 Gunnarsson T, Krassioukov AV, Sarjeant R, Fehlings MG. Real-time continuous intraoperative electromyographic and somatosensory evoked potential recordings in spinal surgery: correlation of clinical and electrophysiologic findings in a prospective, consecutive series of 213 cases. Spine (Phila Pa 1976) 2004;29(6):677–684
14 Bartley K, Woodforth IJ, Stephen JP, Burke D. Corticospinal volleys and compound muscle action potentials produced by repetitive transcranial stimulation during spinal surgery. Clin Neurophysiol 2002;113(1):78–90
15 Langeloo DD, Lelivelt A, Louis Journée H, Slappendel R, de Kleuver M. Transcranial electrical motor-evoked potential monitoring during surgery for spinal deformity: a study of 145 patients. Spine (Phila Pa 1976) 2003;28(10):1043–1050
16 Langeloo DD, Journée HL, de Kleuver M, Grotenhuis JA. Criteria for transcranial electrical motor evoked potential monitoring during spinal deformity surgery A review and discussion of the literature. Neurophysiol Clin 2007;37(6):431–439
17 Lang EW, Chesnut RM, Beutler AS, Kennelly NA, Renaudin JW. The utility of motor-evoked potential monitoring during intramedullary surgery. Anesth Analg 1996;83(6):1337–1341
18 Luk KD, Hu Y, Wong YW, Cheung KM. Evaluation of various evoked potential techniques for spinal cord monitoring during scoliosis surgery. Spine (Phila Pa 1976) 2001;26(16):1772–1777
19 Paradiso G, Lee GY, Sarjeant R, Hoang L, Massicotte EM, Fehlings MG. Multimodality intraoperative neurophysiologic monitoring findings during surgery for adult tethered cord syndrome: analysis of a series of 44 patients with long-term follow-up. Spine (Phila Pa 1976) 2006;31(18):2095–2102
20 Macdonald DB. Intraoperative motor evoked potential monitoring: overview and update. J Clin Monit Comput 2006;20(5):347–377
21 Weinzierl MR, Reinacher P, Gilsbach JM, Rohde V. Combined motor and somatosensory evoked potentials for intraoperative monitoring: intra- and postoperative data in a series of 69 operations. Neurosurg Rev 2007;30(2):109–116, discussion 116
22 Sutter M, Eggspuehler A, Grob D, et al. The diagnostic value of multimodal intraoperative monitoring (MIOM) during spine surgery: a prospective study of 1,017 patients. Eur Spine J 2007;16 (Suppl 2):S162–S170
23 Matsuyama Y, Shimiya K, Ando M, et al. The current situation and alarm points of intraoperative spinal cord monitoring—a multi-institution survey conducted by the Monitoring Committee of the Japanese Society for Spine Surgery and Related Research. Clinical Brain Wave 2009;51(5):286–291
24 Taniguchi M, Cedzich C, Schramm J. Modification of cortical stimulation for motor evoked potentials under general anesthesia: technical description. Neurosurgery 1993;32(2):219–226
25 Calancie B, Harris W, Brindle GF, Green BA, Landy HJ. Threshold-level repetitive transcranial electrical stimulation for intraoperative monitoring of central motor conduction. J Neurosurg 2001;95(2, Suppl):161–168
26 Calancie B, Harris W, Broton JG, Alexeeva N, Green BA. "Threshold-level" multipulse transcranial electrical stimulation of motor cortex for intraoperative monitoring of spinal motor tracts: description of method and comparison to somatosensory evoked potential monitoring. J Neurosurg 1998;88(3):457–470
27 Accadbled F, Henry P, de Gauzy JS, Cahuzac JP. Spinal cord monitoring in scoliosis surgery using an epidural electrode. Results of a prospective, consecutive series of 191 cases. Spine (Phila Pa 1976) 2006;31(22):2614–2623
28 Jones SJ, Harrison R, Koh KF, Mendoza N, Crockard HA. Motor evoked potential monitoring during spinal surgery: responses of distal limb muscles to transcranial cortical stimulation with pulse trains. Electroencephalogr Clin Neurophysiol 1996;100(5):375–383
29 Macdonald DB, Al Zayed Z, Al Saddigi A. Four-limb muscle motor evoked potential and optimized somatosensory evoked potential monitoring with decussation assessment: results in 206 thoracolumbar spine surgeries. Eur Spine J 2007;16(Suppl 2):S171–S187
30 Eggspuehler A, Sutter MA, Grob D, Jeszenszky D, Dvorak J. Multimodal intraoperative monitoring during surgery of spinal deformities in 217 patients. Eur Spine J 2007;16(Suppl 2):S188–S196

Age-Related Surgical Outcomes of Laminoplasty for Cervical Spondylotic Myelopathy

Takafumi Maeno[1] Shinya Okuda[1] Tomoya Yamashita[1] Tomiya Matsumoto[1] Ryoji Yamasaki[1] Takenori Oda[2] Motoki Iwasaki[1]

[1] Department of Orthopedic Surgery, Osaka Rosai Hospital, Sakai, Japan
[2] Department of Orthopedic Surgery, Sumitomo Hospital, Osaka, Japan

Address for correspondence Takafumi Maeno, MD, Osaka Rosai Hospital, 1179-3 Nagasone-cho, Kita-ku, Sakai Osaka, Japan 591-8025 (e-mail: DZM02716@nifty.ne.jp).

Global Spine J 2015;5:118–123.

Abstract

Study Design Retrospective clinical study.
Objective To investigate the age-related surgical outcomes of laminoplasty.
Methods One hundred patients who underwent an en bloc laminoplasty for cervical spondylotic myelopathy from 2004 to 2008 and were followed for at least 1 year were included in this study. The clinical outcomes were assessed with the Japanese Orthopaedic Association (JOA) score. Acquired points (postoperative JOA score minus preoperative JOA score) were also calculated. To investigate the age-related effect for laminoplasty, two analyses were conducted: (1) the correlation between age and clinical outcome; and (2) the clinical outcomes by decade. Patients were divided into four groups according to their age at the time of operation as follows: group 50s, 50 to 59 years old; group 60s, 60 to 69 years; group 70s, 70 to 79 years; and group 80s, 80 to 89 years. The pre- and postoperative JOA scores, acquired points, preoperative comorbidities, and postoperative complications were then compared among the groups.
Results Significant correlations were detected between age and JOA scores at the preoperative ($p = 0.03$), postoperative maximum ($p < 0.0001$), and final assessments ($p < 0.0001$). An age-related decline of JOA scores was observed over all periods. The analysis by decades showed the same results. On the other hand, the significant differences were not found for acquired points over all periods by either method. The preoperative comorbidities of hypertension and diabetes mellitus increased with age. Delirium was more common postoperatively in elderly patients.
Conclusions Although an age-related decline of JOA scores was found over all periods, there were no severe sequelae and no differences in the acquired points that were age-related.

Keywords
- cervical spondylotic myelopathy
- elderly patient
- laminoplasty
- age-related

Introduction

Cervical laminoplasty is a surgical option for patients with compression myelopathy, such as cervical spondylotic myelopathy (CSM), ossification of the posterior longitudinal ligament (OPLL), and cervical disk herniation (CDH).[1–14] As the number of elderly individuals in the population is increasing, surgical treatment for cervical myelopathy in elderly patients is becoming a great concern. Although many authors have reported age-related surgical outcomes for myelopathy due to

received
July 7, 2014
accepted after revision
November 10, 2014
published online
December 8, 2014

DOI http://dx.doi.org/10.1055/s-0034-1396759.
ISSN 2192-5682.

cervical lesions, there were some limitations in terms of the surgical methods, such as anterior fixation, laminectomy, and laminoplasty,[15–19] and different pathologies, such as CSM, OPLL, and CDH.[16,17,19,20] Furthermore, some publications have reported the surgical outcomes of cervical laminoplasty for CSM in elderly patients, but their definitions of *elderly* varied.[7,14,21–26] No standard definitions of *elderly* might lead to paradoxical conclusions. In fact, some authors have reported poorer outcomes in elderly patients than in younger patients,[26] whereas others found no differences among the age groups.[21,23,25] To investigate the age-related surgical outcomes of laminoplasty, analyzing the correlation between age and the clinical outcomes appeared reasonable. Therefore, the purpose of this study was to investigate the age-related surgical outcomes of laminoplasty using two types of analysis without defining *elderly*.

Materials and Methods

Patient Population

From 2004 to 2008, 124 consecutive laminoplasties for CSM were performed at our institution. One hundred patients (50 to 86 years old) who were followed for at least 1 year were included in this study. The follow-up rate was 81%. Patients with rheumatoid arthritis, hemodialysis, OPLL, psychosis, and other neurogenic diseases were excluded. The patients were divided into four groups according to their age at the time of operation: group 50s, 50 to 59 years old (21 patients); group 60s, 60 to 69 years (32 patients); group 70s, 70 to 79 years (37 patients); and group 80s, 80 to 89 years (10 patients). Patients who were under 50 years old (4 cases) and above 89 years old (2 cases) were excluded. The average age of each group was 56, 64.1, 73.3, and 82.9 years, respectively. The symptom duration was investigated by reviewing the clinical records. The average symptom durations were 3.1, 2.7, 3.9, and 2.1 years, respectively. The average follow-up durations were 4.0, 4.4, 3.8, and 4.5 years, respectively (►**Table 1**). There were no significant differences among these groups in symptom duration and follow-up period.

Surgical Technique

In this study, all patients underwent an en bloc laminoplasty that was introduced by Itoh and Tsuji.[8] The surgical sites were: C3–C5 in 1 case, C3–C6 in 13 cases, C3–C7 in 6 cases, and C4–C7 in 1 case in group 50s; C3–C6 in 24 cases, C3–C7 in 7 cases, and C4–C6 in 1 case in group 60s; C3–C6 in 20 cases, C3–C7 in 12 cases, C3–T1 in 1 case, C4–C7 in 2 cases, C5–C6 in 1 case, and C5–C7 in 1 case in group 70s; and C3–C6 in 9 cases and C3–C7 in 1 case in group 80s. After surgery, the patients wore a soft cervical collar, which they were allowed to remove within a week. The mean operation time was 119 minutes (group 50s, 128 minutes; group 60s, 118 minutes; group 70s, 116 minutes; and group 80s, 115 minutes), and the mean estimated blood loss during the laminoplasty was 153 mL (group 50s, 108 mL; group 60s, 164 mL; group 70s, 164 mL; and group 80s, 173 mL). There were no significant differences among these groups in the operation time and blood loss (data not shown).

Clinical Assessment

The clinical outcomes were assessed using the scoring system proposed by the Japanese Orthopaedic Association (JOA). Briefly, the JOA score consists of upper extremity function (4 points), lower extremity function (4 points), sensory (6 points), and urinary bladder function (3 points). A normal JOA score was 17 points.

The clinical assessments were performed for all patients before surgery; at 1, 6, and 12 months after surgery; and then annually thereafter. The acquired points were also calculated in each period. Furthermore, the preoperative comorbidities and postoperative complications were investigated.

Statistical Analysis

To investigate the correlations between age and the clinical outcomes, the Spearman rank correlation coefficient was used for each factor. Values of $p < 0.05$ indicated significance. The Bonferroni test was performed for analyzing the differences among the four groups. Values of $p < 0.005/6 = 0.0083$ indicated significance for this analysis.

Results

Age and JOA Scores

Significant negative correlations were detected between age and the total JOA scores at the preoperative ($p = 0.03$), postoperative maximum ($p < 0.0001$), and final assessments

Table 1 Patient demographic data

	Group 50s	Group 60s	Group 70s	Group 80s
Number	21	32	37	10
Age	56	64.1	73.3	82.9
Male/female	14/7	25/7	24/13	6/4
Symptom duration (y)	3.1	2.7	3.9	2.1
F/U (y)	4.0	4.4	3.8	4.5
HT (%)	5 (24)	11 (34)	20 (54)	8 (80)
DM (%)	3 (14)	7 (22)	12 (32)	5 (50)

Abbreviations: DM, diabetes mellitus; HT, hypertension; F/U, follow-up.

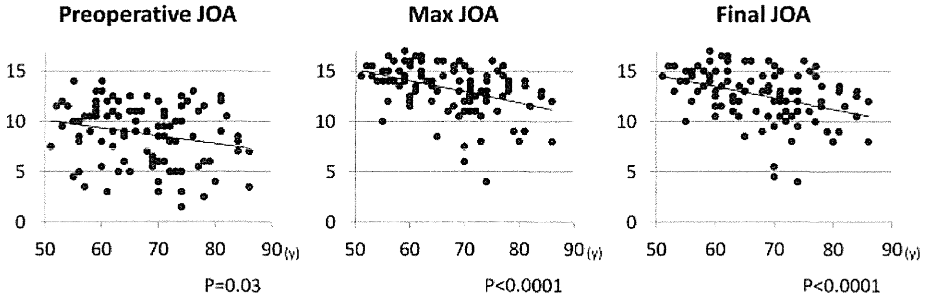

Fig. 1 Spearman rank correlation coefficient between age and Japanese Orthopaedic Association (JOA) score.

($p < 0.0001$; ►**Fig. 1**). For the upper extremity function, significant negative correlations were also detected between age and the JOA scores at the preoperative ($p = 0.0028$), postoperative maximum ($p < 0.0001$), and final assessments ($p = 0.0002$; data not shown). Similarly, with regard to the lower extremity function, significant negative correlations were detected between age and the JOA scores of the lower extremities at the preoperative ($p = 0.0037$), postoperative maximum ($p = 0.0003$), and final assessments ($p = 0.0004$; data not shown). In terms of the analysis by decade, the average total JOA scores at the preoperative, postoperative maximum, and final assessments were 9.7, 14.5, and 14.1 points in group 50s; 9.1, 13.8, and 13.1 points in group 60s; 7.9, 12.3, and 11.6 points in group 70s; and 8.2, 11.5, and 11.1 points in group 80s, respectively (►**Fig. 2**). Although no significant differences were detected in the preoperative JOA scores between the groups, those at the postoperative maximum and final assessments of groups 70s and 80s were significantly lower than those of groups 50s and 60s. Regarding the upper extremity function, the average JOA scores at the preoperative, postoperative maximum, and final assessments were 2.5, 3.6, and 3.5 points in group 50s; 2.0, 3.3, and 3.1 points in group 60s; 1.7, 3.0, and 2.8 points in group 70s; and 1.5, 2.8, and 2.7 points in group 80s, respectively (►**Fig. 2**). The average JOA scores of the upper extremities at the preoperative, postoperative maximum, and final assessments were significantly lower for group 70s and 80s than for group 50s. With regard to lower extremity function, the average JOA scores at the preoperative, postoperative maximum, and final assessments were 1.8, 2.9, and 2.8 points in group 50s; 1.7, 3.0, and 2.6 points in group 60s; 1.3, 2.3, and 2.1 points in group 70s; and 1.1, 1.9, and 1.8 points in group 80s, respectively (►**Fig. 2**). Although no significant differences were detected in the preoperative JOA scores between the groups, those at the postoperative maximum were significantly lower for groups 70s and 80s than for groups 50s and 60s, and those at the final assessments were significantly lower for groups 70s and 80s than for group 50s.

Age and Acquired Points

No correlations were detected between age and the acquired points in each category through all periods (data not shown). In terms of the analysis by decade, the average total acquired points at the postoperative maximum and final assessments were 4.8 and 4.5 in group 50s, 4.8 and 4.0 in group 60s, 4.4 and 3.6 in group 70s, and 3.1 and 2.9 in group 80s, respectively (►**Fig. 3**). Regarding the upper extremity function, the average acquired points at the postoperative maximum and final assessments were 1.0 and 1.0 in group 50s, 1.4 and 1.1 in group 60s, 1.3 and 1.1 in group 70s, and 1.3 and 1.2 in group 80s, respectively. With regard to the lower extremity function, the average acquired points at the postoperative

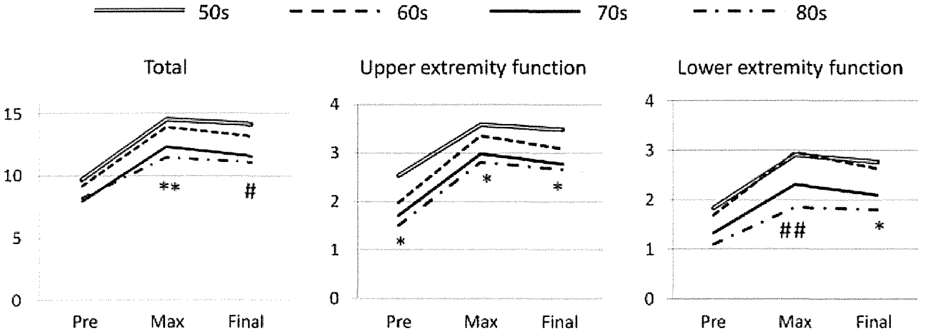

Fig. 2 Japanese Orthopaedic Association score. *Group 50s versus group 70s, group 50s versus group 80s: $p < 0.0083$. **Group 50s versus group 70s, group 50s versus group 80s, group 60s versus group 70s, group 60s versus group 80s: $p < 0.0083$. #Group 50s versus group 70s, group 50s versus group 80s, group 60s versus group 70s: $p < 0.0083$. ##Group 50s versus group 80s, group 60s versus group 70s, group 60s versus group 80s: $p < 0.0083$.