Current Trends in Intraoperative Spinal Cord Monitoring: A Survey Analysis among Japanese Expert Spine Surgeons

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Abstract:

Introduction: Although intraoperative spinal neuromonitoring (IONM) is recommended for spine surgeries, there are no guidelines regarding its use in Japan, and its usage is mainly based on the surgeon's preferences. Therefore, this study aimed to provide an overview of the current trends in IONM usage in Japan.

Methods: In this web-based survey, expert spine surgeons belonging to the Japanese Society for Spine Surgery and Related Research were asked to respond to a questionnaire regarding IONM management. The questionnaire covered various aspects of IONM usage, including the preferred modality, operation of IONM, details regarding muscle-evoked potential after electrical stimulation of the brain (Br(E)-MsEP), and need for consistent use of IONM in major spine surgeries.

Results: Responses were received from 134 of 186 expert spine surgeons (response rate, 72%). Of these, 124 respondents used IONM routinely. Medical staff rarely performed IONM without a medical doctor. Br(E)-MsEP was predominantly used for IONM. One-third of the respondents reported complications, such as bite injuries caused by Br(E)-MsEP. Interestingly, two-thirds of the respondents did not plan responses to alarm points. Intramedullary spinal cord tumor, scoliosis (idiopathic, congenital, or neuromuscular in pediatric), and thoracic ossification of the posterior longitudinal ligament were representative diseases that require IONM.

Conclusions: IONM has become an essential tool in Japan, and Br(E)-MsEP is a predominant modality for IONM at present. Although we investigated spine surgeries for which consistent use of IONM is supported, a cost-benefit analysis may be required.

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Introduction

Spine surgery always carries an inherent risk of injury to critical neural structures, and the rate of neurological complications associated with spine surgery ranges from 1.3% to 31%[1,2]. Neurological complications may occur due to the direct mechanical force applied to the spinal cord during the intervention or indirect ischemic changes, such as cord distraction/compression, during corrective maneuvers[3]. Intraoperative spinal neuromonitoring (IONM) is a useful tool for reducing neurological complications and accurately detecting spinal cord injury[4,5]. As a result, the use of IONM during spine surgery is steadily increasing worldwide[6,7].

IONM can be performed using several modalities, such as muscle-evoked potential after electrical stimulation of the brain (Br(E)-MsEP), somatosensory evoked potentials after electrical stimulation of the peripheral nerve (SEP), spinal cord-evoked potential after electrical stimulation of the brain (Br(E)-SCEP [D-wave]), spinal cord-evoked potential after stimulation of the spinal cord (Sp(E)-SCEP), spontaneous electromyography (EMG), triggered EMG, and muscle-evoked potential after electrical stimulation of the spinal cord (Sp(E)-MsEP)[8]. Multimodal IONM has been previously reported to be more helpful than a single modality approach and is recommended in spine surgery[9,10].

Although IONM is an attractive option to maximize the safety of spinal procedures and limit the risk of neurological complications, the availability and type of monitoring methods may vary among institutions or spine surgeons' preferences in Japan. Other factors potentially influencing the use of IONM include surgeon experience, training background, and resource availability. Although two previous reports have described the status of IONM usage in Japan[11,12], they were written in Japanese. Therefore, we identified the need to re-investigate the current IONM situation in Japan and publish the findings in English.

The primary aims of this study were 1) to clarify the current trends of IONM in Japan, 2) to evaluate the details of IONM in our country, and 3) to compare past and current IONM. An additional secondary aim was to evaluate the necessity of IONM for several spinal diseases.

Materials and Methods

Study design

We conducted a web-based survey from September 1 to September 30, 2021. The questionnaire (Table 1, available online) was sent to all board members of the Japanese Society for Spine Surgery and Related Research (JSSR) via email. Since the data presented in this survey did not include patient information, the need for informed consent was waived. The doctors who participated in the survey were briefed about the possibility of opting out of the study. The board members of the JSSR consisted of 186 expert spine surgeons from all regions of Japan. The number of members of the JSSR was 3,865 as of January 2021. Board members were selected based on their experience in spine surgery, publications on spine research, and contributions to the JSSR.

Details of the questionnaire

Background questions included years of experience in spine surgery, years of experience in IONM, and the number of spine surgeries performed annually before the COVID-19 pandemic. The members were also asked about commonly used monitoring IONM modalities such as Br(E)-MsEP, SEP, D-wave, Sp(E)-SCEP, and spontaneous EMG. For Br (E)-MsEP monitoring, we surveyed the following details: 1) the wave amplitude reduction that was considered an alarm point; 2) management (preparation, intraoperative management, judgment of wave amplitudes); 3) the device and number of channels used for Br(E)-MsEP monitoring; and 4) the experiences and details of complications related to Br (E)-MsEP monitoring and steps for prevention of complications. We also asked the respondents to clarify how they managed situations in which adequate wave amplitudes were not obtained from Br(E)-MsEP monitoring from the initial operation.

The final question was whether respondents believed IONM should be the standard of care for various types of spine surgeries, such as those for adult spinal deformity (ASD), scoliosis (idiopathic, congenital, or neuromuscular in pediatric patients), cervical ossification of the posterior longitudinal ligament (OPLL), cervical spondylotic myelopathy (CSM), thoracic OPLL, intramedullary spinal cord tumor (IMSCT), extramedullary spinal cord tumor (EMSCT), cauda equina tumor, and lumbar spinal canal stenosis (LSS) (Table 1).

Results

Survey respondents

Responses were received from 134 of the 186 (72%) expert spine surgeons who were invited to complete the questionnaire. All respondents had sufficient experience with spine surgery as follows: 102 respondents, ≥20 years; 24 re-

Table 1. Details of the Survey.

Demographic	Experience in IONM (yr)	0–5 6–10 11–15 16–20 ≥21
	Number of spine surgeries performed each year before the COVID-19 pandemic	Free description
	Experience in performing spine surgery (yr)	6–10 11–15 16–19 ≥20
	The number of spine surgeons in the responder's institution (person)	1–2 3–4 ≥5
IONM implementation status	Does your institution use IONM for spine surgeries?	Less than half of the spine surgeries were performed with IONM More than half of the spine surgeries were performed with IONM All spine surgeries were performed with IONM IONM was not used Others (free description)
	Which IONM modality is used at your institution? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG Sp-SCEP D-wave Others (free description)
	Which company's equipment do you use for IONM? (Multiple selections are possible)	Nihon Kohden NuVasive Medtronic Others (free description)
	Who prepares the IONM system before spine surgeries at your institution? (Multiple selections are possible)	Orthopedic surgeon Nurse Anesthetist Medical technologists Clinical engineers Others (free description)
	Who manages IONM, especially in Br(E)-MsEP, during spine surgeries at your institution? (Multiple selections are possible)	Orthopedic surgeon Nurse Anesthetist Medical technologists Clinical engineers Others (free description)
	Who evaluates alarm points on IONM, especially in Br(E)-MsEP, during spine surgeries at your institution? (Multiple selections are possible)	Orthopedic surgeon Nurse Anesthetist Medical technologists Clinical engineers Others (free description)

Table 1. Details of the Survey (continued).

Br(E)-MsEP implementation status	Which alarm point do you use for Br(E)-MsEP?	More than 50% reduction More than 70% reduction Alarm point changes according to the type of surgery Unknown Others (free description)
	How many channels do you use in Br(E)-MsEP?	16 8–14 4 Unknown Others (free description)
	Have you ever experienced any complications related to Br(E)-MsEP?	Yes No
	Which complications have you experienced? (Multiple selections are possible)	Buccal mucosa injuries Tongue injuries Tooth injury Epilepsy seizures Others (free description)
	Please list your countermeasures to avoid complications of Br(E)-MsEP (Multiple selections are possible).	Minimize the intensity and frequency of transcranial stimulation Fill the oral cavity with gauze or bite block Avoid using IONM for patients with a history of epilepsy Others (free description)
	Do you decide the management of alarm points on Br(E)-MsEP in advance?	Yes, I determine it in advance No, I do not determine it in advance Unknown Others (free description)
	How do you manage spine surgery in cases with inadequate wave amplitudes on Br(E)-MsEP before surgery?	Change the monitored muscles or the electrode position to obtain adequate wave amplitude at least once Add SEP and start surgery Maintain Br(E)-MsEP and start surgery without Br(E)-MsEP Postpone surgery Unknown Others (free description)
Awareness survey regarding the necessity of IONM for several spine surgeries	Does correction surgery for ASD require IONM?	Yes No
	Which IONM modality should be used for correction surgery of ASD? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG D-wave Others (free description)
	Does correction surgery for scoliosis (adolescent or syndromic or congenital) require IONM?	Yes No
	Which IONM modality should be used for correction surgery of scoliosis (adolescent or syndromic or congenital)? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG D-wave Others (free description)
	Does decompression surgery for cervical OPLL require IONM?	Yes No
	Which IONM modality should be used for decompression surgery for cervical OPLL? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG D-wave Others (free description)

Table 1. Details of the Survey (continued).

Awareness survey regarding the necessity of IONM for several spine surgeries	Does decompression surgery for CSM require IONM?	Yes No
	Which IONM modality should be used for decompression surgery for CSM? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG D-wave Others (free description)
	Does decompression and fusion surgery require thoracic OPLL need IONM?	Yes No
	Which IONM modality should be used for decompression and fusion surgery for thoracic OPLL? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG D-wave Others (free description)
	Does resection surgery for IMSCT require IONM?	Yes No
	Which IONM modality should be used for resection surgery for IMSCT? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG D-wave Others (free description)
	Does resection surgery for EMSCT need IONM?	Yes No
	Which IONM modality should be used for resection surgery for EMSCT? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG D-wave Others (free description)
	Does resection surgery for cauda equina tumor need IONM?	Yes No
	Which IONM modality should be used for resection surgery for cauda equina tumor? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG D-wave Others (free description)
	Does decompression surgery for LSS need IONM?	Yes No
	Which IONM modality should be used for decompression surgery for LSS? (Multiple selections are possible)	Br(E)-MsEP SEP Spontaneous EMG D-wave Others (free description)

Abbreviations: IONM, intraoperative neuromonitoring; SEP, somatosensory evoked potentials; EMG, electromyography

spondents, 16-19 years; 7 respondents, 11-15 years; and 1 respondent, 6-10 years. The respondents' experience with IONM was as follows: 42 respondents, ≥21 years; 25 respondents, 16-20 years; 31 respondents, 11-15 years; 23 respondents, 6-10 years; 5 respondents, 0-5 years; and 8 respondents, no IONM usage (Table 2). Furthermore, two respondents did not perform spine surgery at all. Thus, a total of 124 respondents (92.5%) regularly used IONM during spine surgery (Fig. 1).

Status of IONM usage

Several types of IONM modalities are available at present. Our survey showed that the most preferred modality for IONM was Br(E)-MsEP (123 respondents, 99%), followed by SEP (53 respondents, 43%), spontaneous EMG (19 respondents, 15%), D-wave (16 respondents, 13%), Sp(E)-SCEP (7 respondents, 6%), triggered EMG (2 respondents, 2%), and Sp(E)-MsEP (1 respondent, 1%). The frequency of

Table 2. Relationship between Experience in IONM and That in Spine Surgery.

		Experience in IONM (years)						
		More than 21	16–20	11–15	6–10	0–5	Do not use IONM	Total
Experience in spine surgery (years)	More than 20	41	19	16	15	4	7	102
	16–19	1	6	10	5	1	1	24
	11–15	0	0	5	2	0	0	7
	6–10	0	0	0	1	0	0	1
	Total	42	25	31	23	5	8	134

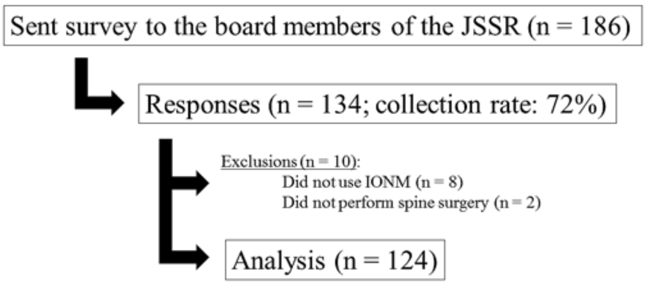

Figure 1. Study design for evaluating current IONM trends. JSSR, Japanese Society for Spine Surgery and Related Research; IONM, intraoperative spinal neuromonitoring

IONM usage was as follows: for less than half of the spine surgeries, 68 respondents (54.8%); more than half of the spine surgeries, 33 respondents (26.6%); for all spine surgeries, 22 respondents (17.7%); for all spine surgeries except emergency cases, 1 respondent (0.8%). The equipment used for IONM was as follows: Nihon Kohden, 90 respondents; NuVasive, 51 respondents; Medtronic, 18 respondents; and unknown, 4 respondents.

Regarding the preparation of IONM before surgery, 48 respondents (38.7%) answered that only the orthopedic surgeon prepared the IONM, 26 (21%) answered that other medical staff members, such as medical technologists, clinical engineers, or nurses, prepared the IONM without medical doctors' assistance, and 50 (40.3%) answered that IONM preparation was performed by staff members involved in orthopedic surgery or anesthesiology.

Regarding the management of IONM during spine surgery, 11 respondents (8.9%) answered that only orthopedic surgeons managed IONM, 85 (68.5%) answered that co-medical staff members, such as medical technologists, clinical engineers, or nurses, managed IONM without the help of medical doctors, and 28 (22.6%) answered that IONM management was performed by staff members involved in orthopedic surgery or anesthesiology.

Regarding the judgment of the alarm point on IONM, 64 respondents (51.6%) answered that the orthopedic surgeon mainly judged the alarm point, 22 (17.7%) answered that co-medical staff members, such as medical technologists, clinical engineers, or nurses, mainly judged the alarm points on IONM, and 38 (30.6%) answered that judgment of alarm points on IONM was performed by staff members involved in orthopedic surgery or anesthesiology.

Thirteen respondents (10.5%) answered that only medical staff members who were not licensed physicians performed preparation, management, and evaluation of alarm points during the IONM operation. The others (89.5%) answered that the orthopedic surgeon joined the IONM operation.

Br(E)-MsEP monitoring

Alarm point

Sixty respondents (48.4%) considered a reduction of more than 50% in the wave amplitudes on Br(E)-MsEP as alarm points, 42 (33.9%) considered a reduction of more than 70% as the alarm point, 19 (15.3%) used different alarm points according to the spine disease, and 3 (2.4%) did not know the exact alarm points used in their institutions.

Number of monitoring channels

Ninety-two respondents (74.2%) used 8-14 channels, 15 (12.1%) used 16 channels, 14 (11.3%) used four channels, 2 (1.6%) used five channels, and 1 (0.8%) used 32 channels.

Experiences of complications associated with the use of Br (E)-MsEP

Although 85 respondents (68.5%) did not encounter any complications associated with Br(E)-MsEP use, 39 (31.4%) did. Among these complications, bite injuries were the most common (tongue injuries, 22 respondents; buccal mucosa injuries, 19 respondents; tooth injury, 16 respondents; lip injuries, 1 respondent). Three respondents encountered scalp burns, while one encountered epileptic seizures. The 39 respondents who encountered complications reported the following prevention methods: filling the oral cavity with gauze or bite block (36 respondents); reducing the intensity and frequency of transcranial stimulation (16 respondents); avoiding Br(E)-MsEP monitoring for patients with a history of epilepsy (10 respondents); other measures (1 respondent).

Response to an alarm point

Forty-three respondents (34.7%) had planned their response to a potential alarm point in advance, while 80 (64.5%) had not. One respondent could not answer this question.

Table 3. Necessity for Consistent Use of IONM in Major Spine Surgeries.

	No. of surgeons needing consistent use of IONM	Type of IONM modality					No. of surgeons needing consistent use of IONM multimodality		No necessity for consistent use of IONM
		Br(E)-MsEP	SEP	Spontaneous EMG	D-wave	Others	Number	Ratio (%)	
1) IMSCT	124	123	82	54	29	3	97	78	0
2) Scoliosis (pediatric)	123	121	60	49	8	0	83	67	1
3) Thoracic OPLL	121	121	64	54	19	2	86	71	3
4) ASD	109	105	41	56	5	1	73	67	15
5) EMSCT (cervical or thoracic)	109	109	54	46	13	3	75	69	15
6) Cervical OPLL	93	92	39	39	9	0	61	66	31
7) Cauda equina tumor	89	87	38	41	3	7	58	65	35
8) CSM	68	68	21	26	2	0	38	56	56
9) LSS	25	23	5	15	N/A	0	15	60	99

ASD, adult spinal deformity; CSM, cervical spondylotic myelopathy; EMSCT, extramedullary spinal cord tumor; IMSCT, intramedullary spinal cord tumor; LSS, lumbar spinal canal stenosis; OPLL, ossification of the posterior longitudinal ligament; IONM, intraoperative neuromonitoring

Management of insufficient wave amplitudes from the beginning of surgery

Regarding cases involving insufficient wave amplitudes from the beginning of surgery, 50 respondents (40.3%) stated that they would continue looking for at least one muscle that could be used for monitoring. In contrast, 39 respondents (31.5%) stated that they would start surgery without Br(E)-MsEP, whereas 22 (17.7%) stated that they would add SEP. Three respondents (2.4%) stated that they would postpone the surgery, while one (0.8%) was unfamiliar with this situation. Nine respondents (7.3%) provided other responses such as adding D-wave monitoring, starting surgery depending on the patient's family's preference, or postponing surgery depending on the nature of the surgery.

Types of spine surgeries for which the respondents recommended the usage of IONM

The respondents were most conscious of the need for IONM in procedures involving the following conditions, listed in descending order of importance: 1) IMSCT, 2) scoliosis (idiopathic, congenital, or neuromuscular in pediatric cases), 3) thoracic OPLL, 4) ASD, 5) EMSCT, 6) cervical OPLL, 7) cauda equina tumor, 8) CSM, and 9) LSS (Table 3). For all spinal disorders presented in the questionnaire, except ASD, Br(E)-MsEP was the most frequently employed IONM method by the respondents, followed by SEP. The necessity for multimodality IONM was a common answer, with an average of 67% (range, 56% [CSM] to 78% [IMSCT]).

Discussion

In this study, we clarified the current trends in IONM use in Japan. Although 10 respondents (7%) did not perform IONM, the majority (93%) used IONM for spine surgery. As expected, the main IONM modality used was Br(E)-MsEP (99%), with SEP as the second (43%). Previously, Tamaki et al.[11] reported that 75% of medical university institutions used some kind of IONM for spine surgery, and the main IONM modality was Sp(E)-SCEP. Seventeen years later, Matsuyama et al.[12] reported that 86% of the surveyed institutions used IONM for spine surgery. The main IONM modality was Br(E)-MsEP (63%), with Sp(E)-SCEP (61%) trailing behind. Furthermore, 39% of the institutions performed SEP monitoring and 28% performed D-wave. Our results may not be directly comparable to previous reports since Tamaki et al.[11] and Matsuyama et al.[12] surveyed institutions, while our study involved a survey of individual expert spine surgeons. Nevertheless, we believe that Br(E)-MsEP is currently the main trend of the IONM modality. Interestingly, the use of SCEP monitoring, such as Sp(E)-SCEP and D-wave, declined for spine surgery in Japan. Meanwhile, the most recent survey in German-speaking countries, including Germany, Austria, and Switzerland, revealed that Br(E)-MsEP and SEP were the most often available modalities (93.7% and 94.3%, respectively), followed by Sp(E)-SCEP (66.5%) and spontaneous EMG (48.1%)[13]. In a survey from Canada conducted more than a decade ago, SEP was the most widely available IONM (65.3%), followed by spontaneous EMG (44.2%) and Br(E)-MsEP (28.4%)[14]. Based on these reports, SEP may play an important role among IONM modalities in other countries compared with Japan.

At present, there are no uniform criteria regarding alarm points for Br(E)-MsEP monitoring in Japan. Langeloo et al.[15] considered an amplitude reduction of 80% or more as a safe criterion that could indicate impending neurologic deficits. Kobayashi et al.[16] recommended the designation of an alarm point as a 70% decrease in amplitude for routine spinal cord monitoring, particularly during surgery for spinal deformity, OPLL, and extramedullary spinal cord tumors.

Luciana et al.[17] used the criteria, which was more than 50% of the baseline amplitudes, to indicate a significant change. Our results showed that most respondents used a 50% or 70% decrease in amplitudes as the alarm point for Br(E)-MsEP.

Regarding the number of monitoring channels, Ito et al.[18] recommended that multi-channel monitoring of at least eight channels should be performed to minimize false-negative cases and maximize the detection rate of motor deficits in muscles. Although four-channel monitoring was the main trend in 2007[18], our survey showed that multi-channel monitoring of more than eight channels was currently the main trend in Japan.

Regarding complications related to IONM, one-third of the respondents encountered complications. Most of them had noted bite injuries. According to past research, the rate of bite injuries reported by anesthesiologists, surgeons, and technicians was 0.13%-0.69%[19-22]. Despite the consistent use of bite blocks as a preventive measure, bite injuries still occur.

Regarding the management of Br(E)-MsEP monitoring, orthopedic surgeons frequently prepared and judged the IONM data during surgery. Co-medical staff, such as medical technologists, clinical engineers, or nurses, operated Br(E)-MsEP during surgery. A small number of respondents stated that co-medical staff alone performed IONM, such as Br(E)-MsEP, from preparation to the judgment of the IONM data during spine surgery (10.5%; 13/124 respondents). This result is contrary to that of a study conducted in Canada more than a decade ago, where most monitoring was perfomed by electrophysiologists[14]. Although a discussion over the primary agents responsible for IONM during spine surgery may be required in the future, it may also be necessary to increase training opportunities as well as the number of medical technologists or clinical engineers who can assist in IONM and thereby reduce the involvement of orthopedic surgeons.

Regarding the measures taken in response to an alarm on Br(E)-MsEP, two-thirds of the respondents had no planned responses for such situations. Although there is no ideal approach to treat alarms on Br(E)-MsEP, we believe that checklists for management of such situations may positively impact care[23,24] since surgeon performance can suffer under stress and time pressure and checklists have been shown to be meaningful aids in these situations. In fact, a previous study showed that 87.7% of respondents who were members of the scoliosis research society used some kind of checklist for managing alerts[25]. Thus, a checklist for responding to alarms in IONM may have to be developed in future studies.

Regarding the responses to inadequate wave amplitudes of Br(E)-MsEP from the initial surgery, the answers from the respondents were interesting. Most respondents did not prefer to postpone surgery and tried to maintain IONM with or without another modality such as SEP or D-wave.

Regarding the categories of spine surgery for which the respondents felt they needed consistent use of IONM, IMSCT was the most common disease in which IONM was required (100%), followed by scoliosis (idiopathic, congenital, or neuromuscular in pediatric cases), thoracic OPLL, and ASD. Although most respondents indicated that IONM should be a standard of care for scoliosis or deformity cases and IMSCT, LSS showed the least indication for IONM. This trend was the same as that in a previous report from Canada[14]. Regardless of the category of spine surgery, more than half of the respondents preferred multimodal IONM (Table 3), which shows high sensitivity and specificity for detecting neurologic injury[9]. Therefore, we believe that multimodal IONM is an ideal, practical, and effective tool to detect neurologic deficits. Particularly, past clinical research has clarified the utility of the combined use of Br(E)-MsEP and D-wave among several types of IONM tools[9,26]. Meanwhile, there is no established consensus regarding the use of IONM during low-risk spine surgery. In our study, only 25 respondents (20.2%) considered that IONM was required in LSS surgery. Although a past report showed that neurological complications were decreased in lumbar laminectomy with IONM[27], a cost-benefit analysis of IONM use in each spine procedure may be an avenue for further study.

Our study had some limitations. First, since the responses were exclusively elicited from JSSR committee members, there was selection bias, raising questions regarding the applicability of these results to general Japanese spine surgeons. Second, although the study covered all regions in Japan, the total number of respondents was relatively small. Third, some respondents belonged to the same institution. This fact may have affected our results.

In conclusion, we conducted a web-based survey to evaluate the current status of IONM use in Japan. Most respondents used IONM as a standard of care for spine surgery. Br(E)-MsEP was the most frequently used IONM technique, although it was common for orthopedic surgeons to be involved with IONM, and complete IONM from preparation to judgment by co-medical staff was reported very rarely. Overall, the findings of our survey support consistent usage of IONM for IMSCT and scoliosis (pediatric) surgeries. Although IONM is less necessary for LSS surgery, it may require a cost-benefit analysis in future studies.

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Ethical Approval: Approved code: #15 from the Japanese Society for Spine Surgery and Related Research.

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