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ORIGINAL ARTICLE - SPINE - OTHER

Indication and technical implementation of the intraoperative neurophysiological monitoring during spine surgeries—a transnational survey in the German-speaking countries

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Abstract

Background Intraoperative neurophysiological monitoring is widely used in spine surgery (sIONM). But guidelines are lacking and its use is mainly driven by individual surgeons' preferences and medicolegal advisements. To gain an overview over the current status of sIONM implementation, we conducted a transnational survey in the German-speaking countries.

Methods We developed a Web interface-based survey assessing prevalence, indication, technical implementation, and general satisfaction regarding sIONM in German, Austrian, and Swiss spine centers. The electronic survey was performed between November 2017 and April 2018, including both neurosurgical and orthopedic spine centers.

Results A total of 463 German, 60 Austrian, and 52 Swiss spine centers were contacted with participation rates of 64.1% (Germany), 68.3% (Austria), and 55.8% (Switzerland). Some 75.9% participating neurosurgical spine centers and only 14.7% of the orthopedic spine centers applied sIONM. Motor- and somatosensory-evoked potentials (93.7% and 94.3%, respectively) were the most widely available modalities, followed by direct wave (D wave; 66.5%). Whereas sIONM utilization was low in spine surgeries for degenerative, traumatic, and extradural tumor diseases, it was high for scoliosis and intradural tumor surgeries. Overall, the general satisfaction within the institutional setting regarding technical skills, staff, performance, and reliability of sIONM was rated as "high" by more than three-quarters of the centers. However, shortage of skilled staff was claimed to be a negative factor by 41.1% of the centers and reimbursement was considered to be insufficient by 83.5%.

Conclusions sIONM availability was high in neurosurgical but low in orthopedic spine centers. Main modalities were motor/somatosensory-evoked potentials and main indications were scoliosis and intradural spinal tumor surgeries. A more frequent sIONM use, however, was mainly limited by the shortage of skilled staff and restricted reimbursement.

Keywords Spine surgery · Intraoperative neurophysiological monitoring · IONM · Prevalence · Survey · Epidemiology

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Abbreviations and acronyms

DACH	Germany, Austria, and Switzerland
DCM	Dorsal column mapping
D wave	Direct wave
DWG	"Deutsche Wirbelsäulengesellschaft" (German Spine Society)
G-DRG	German Diagnosis Related Group system
IMSCT	Intramedullary spinal cord tumor
mMEPs	Muscular motor evoked potentials
ÖGW	"Österreichische Gesellschaft für Wirbelsäulenchirurgie" (Austrian Spine Society)
SGNC	"Schweizerischen Gesellschaft für Neurochirurgie" (Swiss Society of Neurosurgery)
SGS	"Schweizerische Gesellschaft für spinale Chirurgie" (Swiss Society of Spinal Surgery)

sIONM	Spinal intraoperative neurophysiological monitoring
sMEPs	Spinal motor-evoked potentials
SSEPs	Somatosensory-evoked potentials
s/tEMG	Spontaneous/triggered electromyography

Introduction

Even in experts' hands, spine surgery always carries an inherent risk of injury to critical neural structures. To avoid subsequent postoperative neurological deficits, a variety of electrophysiological modalities for intraoperative real-time surveillance have been introduced and evaluated [28, 38].

The most frequently used modalities for spinal procedures are somatosensory- and muscular motor-evoked potentials (SSEPs and mMEPs) as well as free-running/spontaneous or triggered electromyography (sEMG or tEMG) [14]. However, spinal intraoperative neurophysiological monitoring (sIONM) is a continually evolving field and techniques such as spinal motor-evoked potentials (sMEPs or direct wave (D wave)), direct nerve stimulation, pedicle screw stimulation, and dorsal column mapping (DCM) are applied methods in the setting of complex spinal cord surgeries.

Multimodal sIONM, as a current state of the art [30], has been implemented in a wide variety of spine surgeries, ranging from intramedullary spinal cord tumor (IMSCT) resections or spinal deformity correction procedures up to much more frequent but also potentially harmful operations for degenerative diseases such as anterior cervical decompression and fusion [7, 11, 14, 17, 19, 21, 22, 27, 28, 38]. As a consequence, the use of IONM during spine surgery has increased considerably in recent years, for example from 1% of all cases in 2007 to 12% of all cases in 2011 in the USA [18].

Despite this growing trend in favor of the use of sIONM, there are still neither an established consensus nor broadly accepted guidelines. Given the current state of health care economy with rising costs and changes in reimbursement practices, this issue has become particularly relevant when considering the use of IONM in low-risk spinal procedures.

To achieve an overview over the current utilization of sIONM, a transnational survey about the clinical practice of sIONM as well as its technical implementation in German, Austrian, and Swiss spine centers was conducted.

Methods

A total of 16 survey questions were designed to elicit information regarding the numbers of cases and types of spine surgery performed in the respective center with/without sIONM application, techniques and their implementation used for sIONM, occurrence of false-positive/false-negative monitoring events, and the general satisfaction with the current state of monitoring capabilities (Table 1 and Table suppl.). The study was approved by the Institutional Review Board of the Ludwig Maximilians University (LMU), Munich, Germany (AZ17-297) and consents were obtained.

The survey was supported by the "Neurophysiological Section" Executive Committee of the German Society of Neurosurgery ("Deutsche Gesellschaft für Neurochirurgie", DGNC), the German Spine Society ("Deutsche Wirbelsäulengesellschaft," DWG), as well as the Swiss Society of Neurosurgery ("Schweizerischen Gesellschaft für Neurochirurgie," SGNC), the Swiss Society of Spinal Surgery ("Schweizerische Gesellschaft für spinale Chirurgie," SGS), and the Austrian Spine Society ("Österreichische Gesellschaft für Wirbelsäulenchirurgie," ÖGW). Members of each society consist of both neurosurgical and orthopedic spine centers of rural and urban as well as university, non-university, and private practice settings from primary to tertiary medical care level.

Spine centers were identified by address lists provided by the abovementioned societies, additional internet search, and public "hospital requirement plans" of each country, then duplicates were eliminated. The survey was conducted electronically via a Web interface (LimeSurvey™ V2.06+, LimeSurvey GmbH) between November 2017 and February 2018. Survey invitations were directed to the heads of either orthopedic and neurosurgical departments or standalone spine centers. In case of no response, two more requests were sent over the next 2 months; in case of a persistent non-reply, a personal call followed after one additional month. Respondents were assured confidentiality, such neither those responsible for the implementation of the survey nor the abovementioned societies would collect the names of the respondents or in any way connect the answers given to the participants.

"Urban" location was devoted to spine centers in cities with > 100,000 inhabitants. "Primary medical care" was used for spine centers providing locoregional basic and regular care in the private practice setting or in hospitals with capacities < 600 beds, "secondary medical care" for spine centers providing transregional advanced care in hospitals with capacities between 600 and 1500 beds, and "tertiary medical care" for maximum care university and non-university spine centers in large hospitals with capacities > 1500 beds.

Statistics

Frequency distributions and summary statistics were calculated for all questions with categorical answers. An overall response rate for the survey was calculated based on the number

Table 1 Survey questions

Demographics
1.1. Where is your department located at?
1.2. What is the level of care of your department?
1.3. How many spine surgeries are performed in your department per year?
1.4. How many spine surgeries are performed in your department per year utilizing sIONM?
1.5. How many spine surgeries are attributed to the category "degeneration" (w/o sIONM)?
1.6. How many spine surgeries are attributed to the category "trauma" (w/o sIONM)?
1.7. How many spine surgeries are attributed to the category "scoliotic deformation" (w/o sIONM)?
1.8. How many spine surgeries are attributed to the category "tumor" (w/o sIONM)…
… osseous/ extradural?
… intradural/extramedullary?
… intramedullary?
Indications and implementation of sIONM
2. For which type of surgeries would you rate the use of IONM as indispensable?
3. What type of sIONM modalities are generally available in your department?
4.1. Referring to intramedullary lesions: How are they ranked over the spinal segments in terms of frequency?
4.2. In which cases does your department use sIONM for intramedullary surgeries?
5. In case of using sIONM: Which IONM modalities are you usually using for cervical/thoracic/lumbar surgeries?
6. How is the organization of sIONM in your department with regard to…
... the technical implementation (including the placement and fixation of the electrodes, the connection of the electrodes to the stimulation box, etc.)?
… the monitoring?
… the interpretation and evaluation of data?
7. How is the training of the IONM-responsible staff organized in your department?
8. In your opinion: What would be the perfect solution for sIONM implementation?
Grading and evaluation of sIONM
9. With regard to the sIONM of your department: How satisfied are you with the quality of…
… the technical implementation?
… the monitoring?
… the interpretation and evaluation of data?
10. Did you ever have any problems with one or more of the following aspects:
… availability of the sIONM resources?
… technical difficulties with sIONM implementation?
… lack of training of external service providers?
… frequent false-positive IONM results?
… frequent false-negative IONM results?
… others?
11.1. Did you ever witness a false-negative sIONM event?
11.2. How often do false-negative sIONM events in your department occur subjectively?
12.1. Did you ever witness a false-positive sIONM event?
12.2. How often do false-positive sIONM events in your department occur subjectively?
13.1. What was the most pleasant sIONM experience for you/your team?
13.2. What was the most unpleasant sIONM experience for you/your team?
14.1. How should the quality of sIONM be increased in your department?
14.2. How should the quality of sIONM be increased in the German-speaking area?
15. Do you think the DRG-based monetary remuneration per case of sIONM is sufficiently represented in the German-speaking area?
16. In case of a sufficient availability: I think the indications for sIONM in our department…
… should be expanded?
... are sufficient?
... should be reduced?

of individuals that responded and the total number of requests distributed. Subgroup analysis and corresponding relations were assessed using the χ^2 test. All statistical analyses were performed by using SigmaPlot V11.0 (Systat Software, Inc.). Statistical significance was determined by a probability value $p < 0.05$.

Results

Characteristics of contacted spine centers and response rates

Request and response characteristics of the 575 contacted spine centers are displayed in Table 2. The response rate was 63.8% in total and particularly high among the subgroup of university spine centers (79/104).

There were no significant country-specific differences except that the proportion of responding neurosurgical spine centers was higher in Austria ($p_{vs.\_Germany} < 0.001$, $p_{vs.\_Switzerland} < 0.001$), while the proportion of surveyed urban spine centers was higher in Germany ($p_{vs.\_Austria} = 0.024$, $p_{vs.\_Switzerland} = 0.001$).

Furthermore, there were no significant structural differences between responding and non-responding spine centers except that the proportion of primary medical care level centers was lower in the non-responding group compared to the responding group ($p = 0.008$).

sIONM availability rates

One hundred fifty-eight of the 367 (43.1%) responding spine centers claimed to have sIONM principally available. In neurosurgical spine centers, sIONM was available in 75.9% but in only 14.7% of the orthopedic spine centers ($p < 0.001$). Sixty-two percent of the urban spine centers and only 38.0% of the rural spine centers had sIONM available ($p < 0.001$). Availability of sIONM was high in tertiary (67.1%) and secondary (58.6%) medical care level centers but low in primary medical care level centers (28.8%) ($p_{vs.\_tertiary} < 0.001$, $p_{vs.\_secondary} < 0.001$). Of the participating university spine centers, 68.4% had sIONM available (neurosurgical university centers, 97.7%; orthopedic university centers, 31.4%). There were no significant country-specific differences.

Overall, MEPs and SSEPs (93.7% and 94.3%, respectively) were the most often available modalities, followed by D wave (66.5%), free-running EMG (48.1%), direct nerve stimulation (65.8%), and others (e.g., DCM) (14.6%). D wave availability was significantly less prevalent in orthopedic and rural (compared to neurosurgical and urban) spine centers ($p_{neurosurgical\_vs.\_orthopedic} < 0.001$, $p_{urban\_vs.\_rural} = 0.004$) as well as in Austrian (compared to German or Swiss) spine centers ($p_{vs.\_Germany} < 0.001$, $p_{vs.\_Switzerland} < 0.001$).

Table 2 Overall request characteristics and response rates

Characteristics	Requests	Responses
Overall, no. (%)	575 (100.0)	367/575 (63.8)
Country, no. (%)		
Germany	463 (80.5)	297/463 (64.1)
Austria	60 (10.4)	41/60 (68.3)
Switzerland	52 (9.1)	29/52 (55.8)
Specialist discipline, no. (%)		
Neurosurgery	277 (48.2)	170/277 (61.4)
Orthopedics/trauma surgery	298 (51.8)	197/298 (66.1)
Localization, no. (%)		
Urban	283 (49.2)	189/283 (66.8)
Rural	292 (50.8)	178/292 (61.0)
Level of medical care, no. (%)		
Primary medical care	349 (60.7)	215/349 (61.6)
Secondary medical care	119 (20.7)	70/119 (58.8)
Tertiary medical care	107 (18.6)	82/107 (76.6)

Surgical case volumes and sIONM utilization

Of the sIONM-utilizing spine centers, 53.8% performed a total of > 600, 32.3% between 350 and 600, 11.4% between 150 and 350, and 2.5% < 150 operative spine procedures per year. However, the majority of 93% of the spine centers claimed to perform < 150 operative spine procedures with concomitant use of sIONM. The detailed distribution of sIONM utilization in the single case volume categories is shown in Fig. 1a. Figure 1b–g displays the corresponding results of the subgroup analysis with regard to the different categories of operative spine procedures.

The highest rates for sIONM were reported for IMSCT surgery: 82.3% of all responding spine centers utilized sIONM in every circumstance, whereas 8.2% utilized sIONM only in special cases and 9.5% never.

Comparison between (i) neurosurgical and orthopedic spine centers, (ii) the three German-speaking countries, (iii) rural and urban location, and (iv) the three levels of medical care showed the following significant differences: in neurosurgical spine centers, higher surgical case volumes were reported in total and for each category of spine disorders compared to orthopedic spine centers, except for scoliosis surgery which was performed more frequently by orthopedic spine centers; there was no discipline-dependent difference in case volumes of spine procedures for traumatic disorders. Moreover, surgical case volumes for spine tumor surgery, irrelevant whether for extra- or intradural or intramedullary lesions, were higher in tertiary medical care level centers (compared to primary and secondary

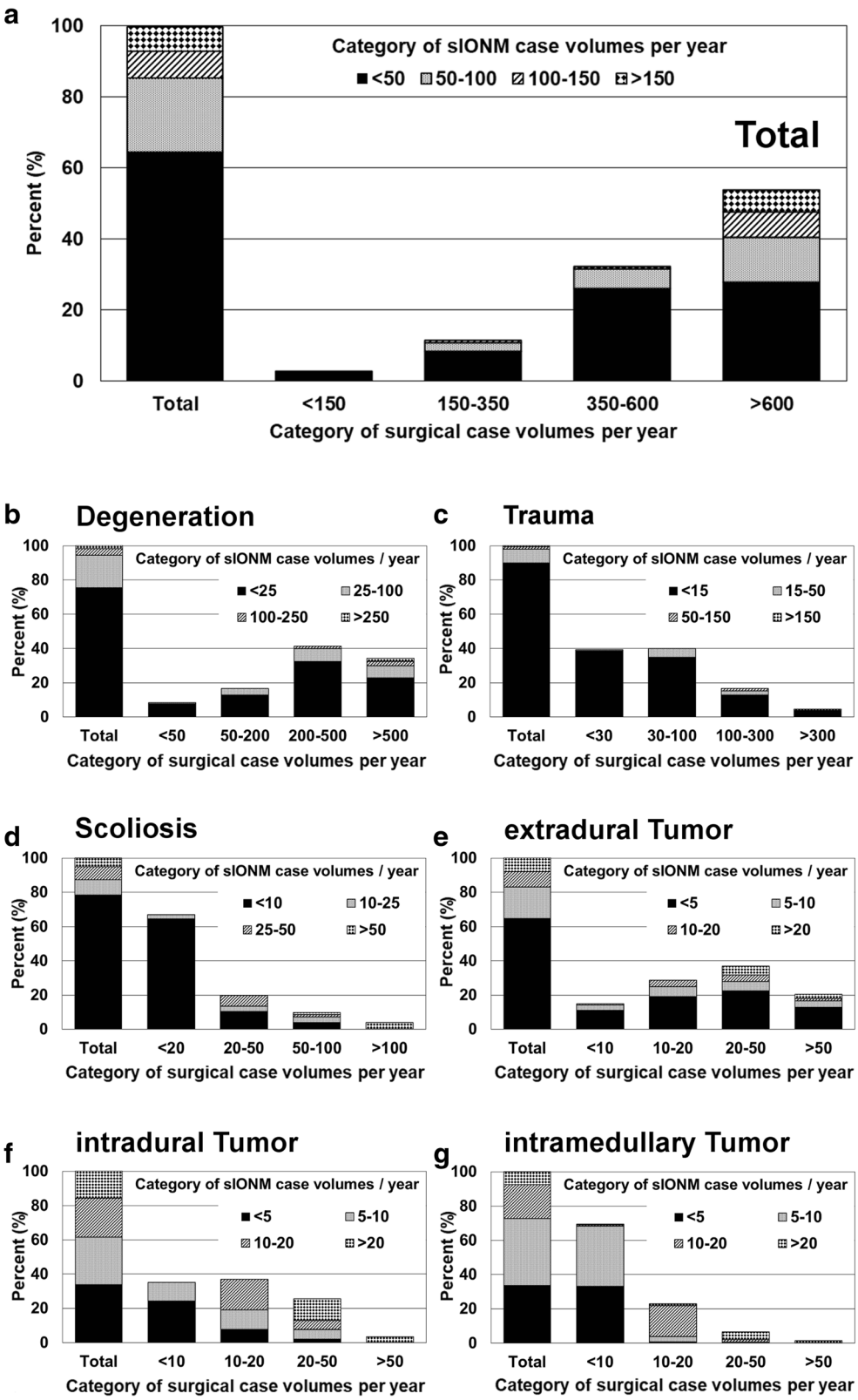

Fig. 1 Categorical distribution of surgical case volumes per year (abscissa) and the percentage of all responding spine centers (ordinate) **a** for all spine disorders, **b** for degenerative spine disorders, **c** for traumatic spine disorders, **d** for corrections of scoliotic deformation, **e** for osseous/extradural spine tumor procedures, and **f** for intradural and **g** for intramedullary spinal cord tumor procedures. The black and different gray-shaded coloration of the single bars displays the distribution of sIONM utilization within the single categories according to the corresponding graph legend. Percentage of sIONM distribution within the single categories is always referred to the total number of responding spine centers and accumulates to the percentage of spine centers of the respective category of surgical case volumes per year

medical care level centers) and in urbanely located spine centers (compared to rural location). There were no significant country-specific differences.

The utilization rates of the different sIONM modalities did not reveal any differences between cervical and thoracic procedures, while in lumbar procedures, EMG and direct nerve

stimulation were significantly more often utilized (each $p < 0.001$). See Table 3.

Implementation, monitoring, and interpretation of sIONM

Implementation, monitoring, and interpretation of sIONM were conducted very heterogeneously in the responding spine centers: Professionals most often in charge for technical implementation of sIONM were specially trained technicians (42.4%), surgical consultants (24.1%), and surgical residents (23.4%). sIONM monitoring was conducted by technicians in 39.2%, surgical consultants in 32.3%, and residents in 22.8% of the cases. However, interpretation of sIONM results was most often assigned to the surgical consultant (62.0%), followed by technicians (29.1%) and surgical residents (24.1%). See Fig. 2a–c.

Monitoring and interpretation of sIONM were more often assigned to non-physician health care professionals (e.g., specially trained technicians) in neurosurgical compared to orthopedic spine centers ($p = 0.020$ and $p = 0.036$, respectively). Likewise, in tertiary compared to primary/secondary medical care level centers ($p_{primary\_vs.\_tertiary} = 0.029$, $p_{secondary\_vs.\_tertiary} = 0.025$, $p_{secondary\_vs.\_tertiary} = 0.031$, $p_{primary\_vs.\_tertiary} = 0.027$, and $p_{secondary\_vs.\_tertiary} = 0.035$, respectively) and in German compared to Swiss (but not to Austrian) spine centers (each $p < 0.001$), sIONM procedure (from technical implementation to monitoring/interpretation) was more often assigned to non-physician health care professionals. However, the far most often professional in charge for sIONM interpretation was named to be the surgical consultant.

The staff responsible for sIONM received education for sIONM by training courses provided by scientific medical societies (46.6% of the responding spine centers), training courses of IONM device manufacturer (8.7%), or in-house training (7.4%). Only 18.9% of the spine centers requested external provider for sIONM services (provided by device companies), occurring significantly more often in orthopedic compared to neurosurgical spine centers ($p = 0.012$).

General satisfaction with sIONM status quo

Independent from the modes of implementation, monitoring, and interpretation of sIONM of the various spine centers, the general satisfaction was consistently high: the individual modality of sIONM was rated to be "very good" or "good" for implementation in 87.9%, monitoring in 79.7%, and interpretation in 81% of the responding spine centers. See Fig. 3a–c.

There were no significant differences of general satisfaction about sIONM quality between neurosurgical and orthopedic spine centers, the three German-speaking countries, rural and urban location, and the three levels of medical care.

Despite the high general satisfaction with sIONM, the insufficient case-related monetary remuneration of sIONM and the missing availability of further sIONM resources were most often criticized (83.5% and 52.5% of the responding spine centers, respectively; see Table 4). In case of sufficient availability of sIONM resources, 57.6% of the spine centers would expand the sIONM utilization in the future. There were no significant differences between neurosurgical and orthopedic spine centers, the three German-speaking countries, rural and urban location, as well as the three levels of medical care.

Discussion

The routine use of IONM during spine surgeries remains highly controversial and varies markedly between centers, often predominantly depending on the individual surgeons' preferences and medicolegal issues. We here investigated the current state of availability, indication, use as well as technical implementation of sIONM in spine centers of Germany, Austria, and Switzerland (DACH).

Structural characteristics and sIONM availability rates

Our survey response rate of over 60% is markedly higher than the previous electronic surveys among surgeons [44] and, therefore, underlines and supports the validity and

Table 3 Utilization rates of sIONM modalities with regard to the procedural spinal level

sIONM modality	Utilization rate, %		
	Cervical surgeries	Thoracic surgeries	Lumbar surgeries
SSEPs	89.9	88.6	76.6
MEPs	84.8	84.2	69.0
D wave	36.1	36.7	–
Direct nerve stimulation (including pedicle screw monitoring)	19.0	20.3	36.7
Free-running EMG	36.1	28.5	44.9
Others (DCM, etc.)	4.4	4.4	5.7

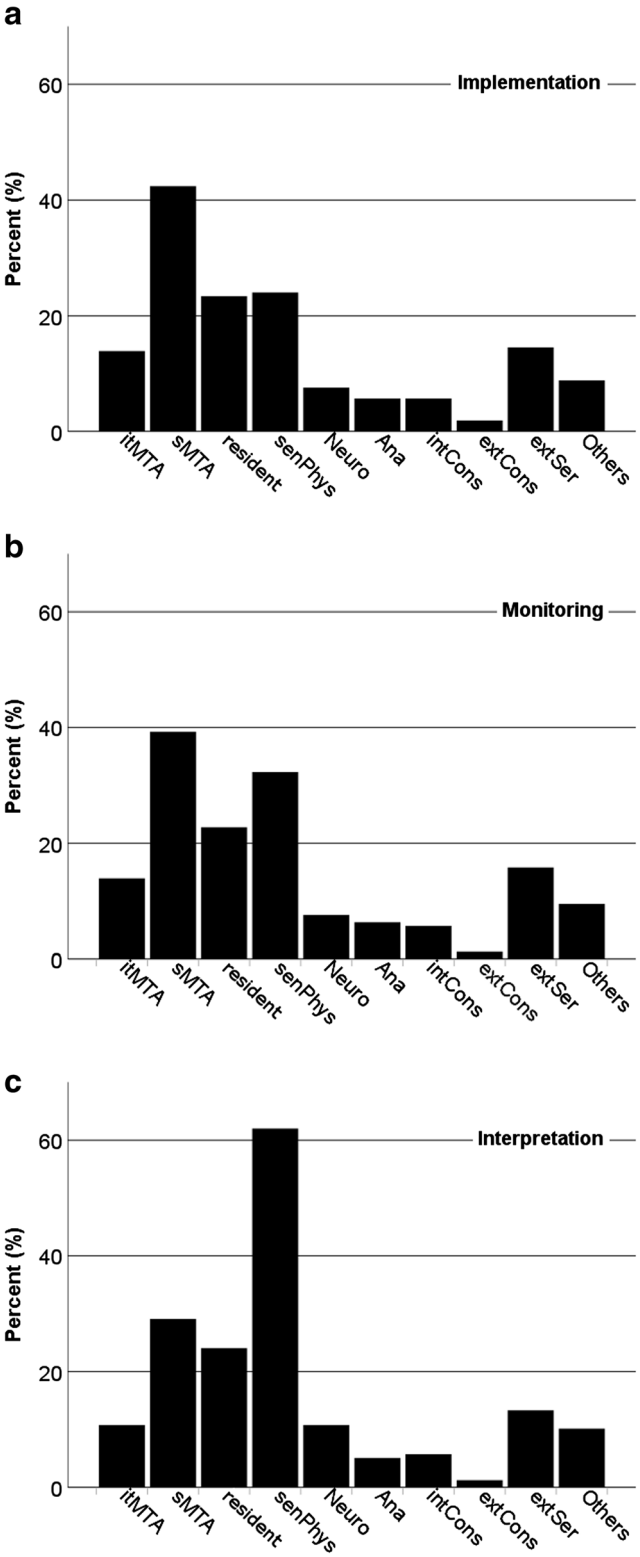

Fig. 2 Organization of sIONM in the single spine centers with regard to **a** implementation, **b** monitoring, and **c** interpretation of sIONM. [itMTA, internally trained staff (e.g., technician, nurse); sMTA, medical technical assistant specially trained in clinical neurophysiology; resident, resident; senPhys, consultant; Neuro, neurologist; ANA, anesthesiologist; intCons, consultation service of the center; extCons, consultation service of an external center; extSer, external service provider]

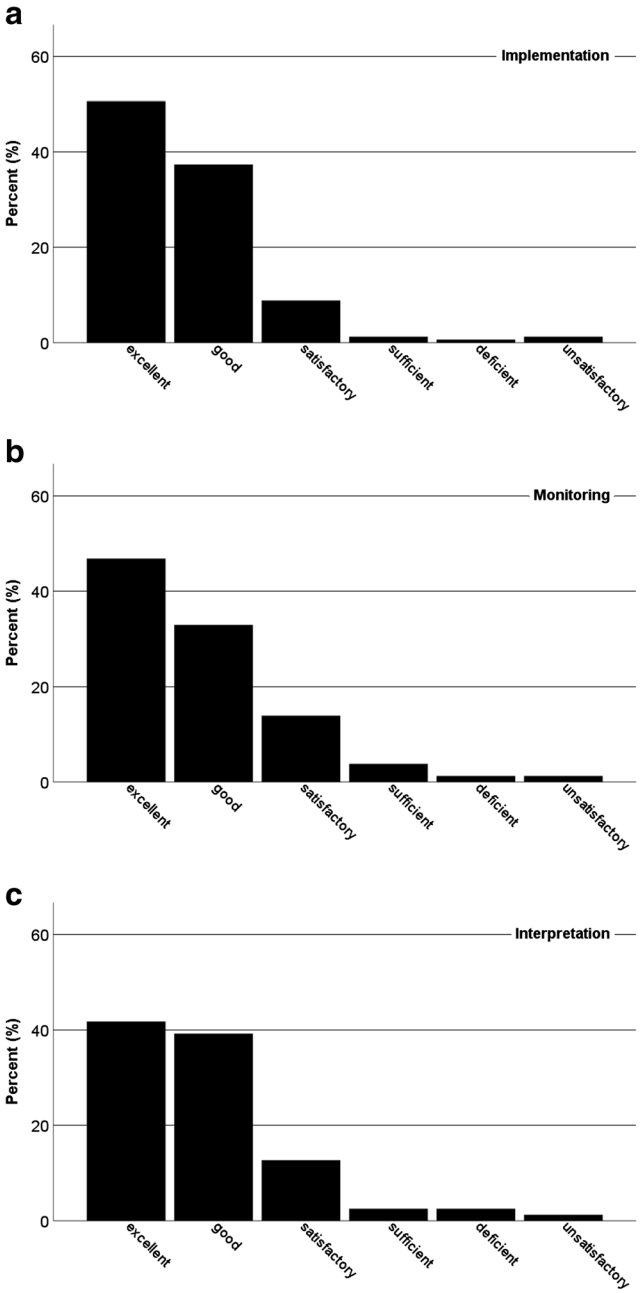

Fig. 3 Distribution of general satisfaction with regard to **a** implementation, **b** monitoring, and **c** interpretation of sIONM

representativity of our results. Differences in baseline characteristics between the three DACH countries were only seen in a slightly higher proportion of neurosurgical spine centers in Austria. The slightly higher proportion of urbanely located spine centers in Germany can be entirely explained with the higher number of cities with more than 100,000 inhabitants in general compared to Austria/Switzerland. There were no further differences in baseline characteristics or in sIONM utilization rates between the three DACH countries in our study, supporting a mere integrative analysis. Moreover, there were no significant structural differences between responding and

Table 4 Criticism of sIONM

Point of criticism	No. of agreeing spine centers per category (%)
Insufficient monetary remuneration	132 (83.5)
Missing availability of sIONM	83 (52.5)
Technical difficulties with sIONM implementation	54 (34.2)
Lack of training of external sIONM staff	23 (14.6)
Frequent false-positive IONM results	22 (13.9)
Frequent false-negative IONM results	9 (5.7)
Others	11 (7.0)

non-responding spine centers, except for a lower proportion of primary medical care level centers in the non-responding group.

We could show that only 43.1% of the responding spine centers claimed to have sIONM principally at disposal, being in line with a 2011 survey of 117 French spinal surgeons with a rate of 36% [13]. Whereas there was no subanalysis undertaken in this French 2011 survey, we could show that this rate, however, markedly differed between the medical specialties: While being very low among orthopedic spine centers (14.7%), IONM is nearly regularly available in neurosurgical spine centers (75.9%). This could possibly be explained by the fact that sIONM was historically introduced by neurosurgeons in Germany, whereas orthopedic spine surgeons embraced sIONM on a larger scale during the past two decades strongly supported by medical device manufacturers. Further, there are more indications for IONM in neurosurgical procedures beyond spine surgeries, justifying medical needs and economical balance for in-house staff.

The availability rate of sIONM was also dependent on the localization and level of medical care, since it was significantly higher in urban (62.0%) and tertiary medical care level centers (67.1%). Since spine procedures with high sIONM utilization rates (e.g., IMSCT or deformity correction in scoliosis) are most often performed in tertiary medical care level centers and these centers are more frequently located in urban locations, it can be assumed that these three criteria interact, although this interaction might be of minor influence. A recently published query of the US National Inpatient Sample database for sIONM between 2008 and 2014 also showed a significantly higher sIONM availability and utilization rate at urban teaching hospitals compared to non-teaching hospitals or rural centers [23].

Our rate of sIONM availability of about 43% and its difference between the medical specialties, however, are in contrast to a Canadian 2004 survey that reported an sIONM availability rate of 95% without any differences between orthopedic and neurosurgical spine centers [26]. These divergent results can be most likely explained by the fact that the polled population in the Canadian 2004 survey consisted of 139 highly specialized spine surgeons at an national experts' conference meeting (14th Annual Disorders of the Spine Meeting, Whistler, Canada) and, therefore, does not allow for an epidemiologically representative assessement of the Canadian general operative spinal health care [26]. This assumption is confirmed by a 2010 published survey among 95 members of the Canadian Spine Society, who report a lower sIONM availability rate of 65.3% [32].

Comparably to the results of previous publications [13, 14, 22, 26, 32], we identified motor- and somatosensory-evoked potentials to be the most widely available sIONM modalities with utilization rates of over 90%. This was true for both the overall analysis and for each spinal segment (cervical, thoracic, lumbar). Furthermore, we found utilization rates of direct nerve stimulation and EMG techniques to be in the range of 20–35% and 30–45% with a maximum in lumbar procedures. This is in line with previous publications that emphasized the importance of pedicle screw monitoring and EMG testing for thoracic and especially lumbar spinal cord instrumentation in both open-exposure and especially percutaneous procedures [16, 22, 31, 33, 34, 42]. According to the anatomical mechanism of action and the restriction to cervical and thoracic localization for applicability [22], about 90% of the participating spine centers did not concede relevant significance to spinal MEPs (D wave) in lumbar procedures; however, it is unclear to us why some spine centers claimed to utilize D wave im lumbar procedures.

Indication-dependent utilization rates and implementation of sIONM

In our survey, participating spine centers ascribed a high significance to sIONM for operative corrections of scoliotic deformation as well as intradural and especially intramedullary spinal cord tumor surgeries (see Fig. 1d, f, g) which matches previous, non-systematic reports [22, 28, 29, 39]. This was equally true for both neurosurgical and orthopedic, urban and rural, as well as primary, secondary, and tertiary medical care level spine centers. The high significance of sIONM for scoliosis surgeries can mostly be explained by the fact that it obviates the need for a burdensome intraoperative wake-up test and ensures a continuous intraoperative real-time surveillance of neurological functions [29]. In contrast, for surgery of degenerative and traumatic spine disorders as well as osseous/extradural spinal neoplasms, we could show that significance of sIONM was rated much smaller by the participating spine centers (see Fig. 1b, c, e), reflecting the abovementioned inconclusive evidence in literature regarding the use of sIONM during spine procedures that have traditionally been viewed mostly as lower-risk surgeries [1–6, 8–10, 12, 15, 18, 20, 24, 25, 35–37, 40, 41, 43].

At present, data are lacking about operational structure of sIONM with regard to implementation, monitoring, and interpretation. Realization of sIONM is highly variable between centers, although mostly technicians, but to a lower extent surgical consultants and residents, are responsible for the technical implementation. As with other diagnostic tests, physicians are responsible for the proper interpretation. However, other professionals (e.g., anesthesiological or neurological consultants or skilled external service providers) and all kinds of possible combinations for the three main parts of sIONM (implementation, monitoring, interpretation) were also reported by individual spine centers. Despite their specialty-owed skills for electrophysiology, neurologists are entrusted with sIONM responsibility in only a small minority of about 5% which might reflect the historical development of sIONM in German-speaking countries. This is in contrast to those countries with the specialization of clinical neurophysiologist, e.g., Spain or Finland, where clinical neurophysiology are conducting sIONM in the majority of the cases. In general, sIONM implementation and monitoring were more often assigned to non-physician health care professionals in spine centers with high sIONM utilization rates, i.e., neurosurgical and tertiary medical care level spine centers, maybe reflecting the fact that high-volume sIONM centers have non-physician professional staff exclusively available for sIONM. However, no matter who is responsible for sIONM implementation, monitoring, and interpretation, the responsibility for the initiation of corrective actions (e.g., irrigation with warm saline solution, etc.) or at last the decision to terminate surgery in persistent critical sIONM findings is always carried by the surgical consultant.

All in all, more than 80% of the spine centers could use sIONM as an in-house service, while only a minority had to recourse to externally qualified IONM professionals. This rate of recourse to externally qualified IONM professionals, however, was higher in orthopedic spine centers and, therefore, seems to correlate with total sIONM case volumes per year and the monetary remuneration of sIONM (see below) which were both lower in orthopedic compared to neurosurgical spine centers. External IONM service is a more recent development in the DACH countries and mostly offered by IONM device manufacturing companies. This is in marked contrast to the USA where specific IONM service companies, not owned by IONM device manufacturing companies, are offering outside IONM services, which cover about 80% of the total IONM there.

sIONM status quo and future aspects

Albeit sIONM was organized in quite different ways, the general satisfaction with the individual solution of implementation, monitoring, and interpretation of sIONM was consistently high in the participating spine centers. We cannot exclude a bias towards positive reporting as difficulties with the technical sIONM implementation were reported by 1 out of 4, frequent occurrence of false-positive sIONM results by 1 out of 10, and frequent occurrence of false-negative sIONM results by one 1 of 20 participating spine centers—each independent from the medical specialty and level of medical care. Especially, the frequent occurrence of false-negative/false-positive reporting can be taken as a hint to sIONM misunderstanding or the lack of neurophysiological skills. The shortage of skilled staff and accordingly sIONM resources was criticized by more than 40% of the participating spine centers.

While the German Diagnosis Related Group (G-DRG) system incorporates remuneration for sIONM exclusively in case of benign spinal (cord) tumor surgery, which is most often performed in neurosurgical (and not in orthopedic) spine centers, the utilization of sIONM in the further abovementioned indications is not rewarded at all, negatively affecting financing of sIONM services in neurosurgical and especially orthopedic spine centers. Utilization of IONM does not generate any reimbursement in either Switzerland or Austria. Therefore, criticism for insufficient case-related monetary remuneration of sIONM was actually reported by over 80% of the participating spine centers with no significant differences between the three DACH countries with their diverse reimbursement systems for sIONM services.

The majority of spine centers would expand the sIONM utilization in the future in case of sufficient availability of sIONM resources. For this, three-quarters of the participating spine centers would prefer a specially trained medical technical assistant to assist a sIONM-qualified physician for routine sIONM use. In terms of the already existing shortage of skilled professionals at the moment, the efforts for more training vacancies for medical technical assistant should be further increased in the present and the future.

Conclusions

All in all, we here present the first comprehensively conducted survey of the current state of sIONM utilization using the example of German-speaking European spine centers. Since one could assume that most of the surgeons represented here were trained in the same system and had exposure to similar mentors during residency and fellowship, we admit that this would perhaps make survey responses more homogenous as compared to a survey that incorporates responses from spine centers in other countries or even continents, e.g., the USA or Canada. Thus, for a more thorough and generalizable illustration of the current state of sIONM utilization, analogous surveys have to be conducted in these countries to close the up-to-date existing lack of corresponding data. Nevertheless, the issue about when and where sIONM is appropriate or essential for use will not be able to be entirely solved by the mere

investigation when spine centers or surgeons are using this tool for specific types of surgery. However, our survey of the current state of sIONM utilization is an essential first step and precondition for the necessary discussion to define better future standards for the reasonable and uniform sIONM in the light of further outcome-based evaluations of the different sIONM techniques.

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Compliance with ethical standards

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all participating spine centers included in the study.

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