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SPECIAL ARTICLE

What are standard monitoring devices for anesthesia in future?

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Abstract
Monitoring the patient's physiological functions is critical in clinical anesthesia. The latest version of the Japanese Society of Anesthesiologists' Guidelines for Safe Anesthesia Monitoring, revised in 2019, covers various factors, including electroencephalogram monitoring, oxygenation, ventilation, circulation, and muscle relaxation. However, with recent advances in monitoring technologies, the information provided has become more detailed, requiring practitioners to update their knowledge. At a symposium organized by the Journal of Anesthesia in 2023, experts across five fields discussed their respective topics: anesthesiologists need to interpret not only the values displayed on processed electroencephalogram monitors but also raw electroencephalogram data in the foreseeable future. In addition to the traditional concern of preventing hypoxemia, monitoring for potential hyperoxemia and the effects of mechanical ventilation itself will become increasingly important. The importance of using AI analytics to predict hypotension, assess nociception, and evaluate microcirculation may increase. With the recent increase in the availability of neuromuscular monitoring devices in Japan, it is important for anesthesiologists to become thoroughly familiar with the features of each device to ensure its effective use. There is a growing desire to develop and introduce a well-organized, integrated "single screen" monitor.

Keywords Electroencephalogram monitoring · Respiratory monitoring · Hemodynamic monitoring · Neuromuscular monitoring · Integrated monitoring

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Abbreviations

EEG	Electroencephalogram
BIS	Bispectral index
PSi	Patient state index
SpO_2	Oxygen saturation
PaO_2	Arterial partial pressure of oxygen
ORi	Oxygen reserve index
IOH	Intraoperative hypotension

Introduction

The latest version of the Japanese Society of Anesthesiologists' Guidelines for Safe Anesthesia Monitoring revised in 2019 serves as the minimum standard to be achieved during anesthesia management. The guidelines require the presence of anesthesiologists and list essential monitoring indices such as oxygenation, ventilation, and circulation. In addition, the guidelines mention equipment such as pulse oximeters, capnometers, and electroencephalogram monitors. Many of the monitors currently in use are advanced and provide far more information than older models. While some have

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proven to be passing fads, others are gaining acceptance and are on their way to becoming standard monitoring devices.

A symposium entitled “What are standard monitoring devices for anesthesia in future?” organized by the Journal of Anesthesia was held at the 70th Annual Meeting of the Japanese Society of Anesthesiologists (Kobe, Japan). The symposium speakers were: Dr. Satoshi Hagihira (Osaka), Professor of Kansai Medical University; Dr. Keisuke Yoshida (Fukushima), Assistant Professor of Fukushima Medical University; Dr. Yoshifumi Kotake (Tokyo), Professor of Toho University Ohashi Medical Center; Dr. Shunichi Takagi (Tokyo), Professor of Nihon University School of Medicine; and Dr. Kenichi Masui (Yokohama), Associate Professor of Yokohama City University.

Each speaker discussed relatively new monitoring devices and indices in their respective fields of expertise, addressing the evidence obtained so far and the future prospects of these technologies potentially becoming standard in the future.

Monitoring the level of hypnosis (Satoshi Hagihira)

The term “depth of anesthesia” has often been used. However, in 1987, Prys-Roberts [1] wrote as follows: “The concept of anesthetic ‘depth’ is ingrained in every anesthetic trainee from the out of training. Yet this concept is illusory, and the anesthetic depth resembles that for the Philosopher’s Stone.”

Anesthesia is now divided into three components: hypnosis, analgesia, and immobilization, and the vague concept of “depth of anesthesia” has become obsolete.

The level of hypnosis is monitored by electroencephalogram (EEG) and evoked potentials. In Japan, several EEG-based monitors are available, including BIS monitor (Medtronic, Dublin, Ireland), Entropy monitor (GE HealthCare, Chicago, IL, USA), and SedLine monitor (Masimo, Irvine, CA, USA). Each monitor calculates the level of hypnosis, indicating it as an index between 0 and 100, with the BIS monitor using Bispectral Index (BIS), the Entropy monitor using SE and RE, and the Sedline monitor using Patient State Index (PSi). It is known that BIS and PSi are calculated EEG sub-parameters combined with coefficients obtained by multivariate analysis of EEG database, which indicates that these indices are predicted values and may include estimation errors. EEG waveforms during anesthesia are widely varied among patients. As a result, EEG-derived parameters vary even among patients at the same level of hypnosis. On the other hand, the pattern of EEG changes related to anesthetic concentration is consistent across all patients. We showed that optimal anesthetic level for surgery is the state in which the activity of waves in the alpha frequency band, known as sleep spindle, is maximized [2]. Steriade et al. [3, 4] showed that the EEG rhythm became that of sleep spindle when the membrane potential of thalamo-cortical projecting neurons was between − 65 to − 55 mV. Additionally, thalamo-cortical projecting neurons receive $GABA_A$ agonistic input from the thalamic reticular nucleus, and since anesthetic drugs enhance the activity of $GABA_A$ neurons, it is considered that changes in the rhythm of EEG reflect the effect of anesthetics. Thus, anesthesiologists need to interpret not only the values displayed on processed EEG monitors but also raw EEG data in the foreseeable future. Auditory evoked potential-based monitors were once available in Japan, but they are no longer available.

Respiratory monitoring (KeisukeYoshida)

The principle of a pulse oximeter was invented by Dr. Takuo Aoyagi in the 1970s, and became widely applied in the 1980s [5]. Pulse oximetry contributes to early detection of hypoxemia by noninvasively and continuously measuring peripheral arterial oxygen saturation (SpO_2), leading to a reduction in associated complications. Therefore, pulse oximetry will continue to play an important role in respiratory monitoring in the future. However, although pulse oximetry is useful for detecting hypoxemia, it is not suitable for detecting hyperoxemia, because SpO_2 reaches close to 100% when arterial partial pressure of oxygen (PaO_2) is ≥ 80 mmHg.

The Oxygen Reserve Index (ORi, Masimo, Irvine, CA, USA) addresses this issue. ORi takes measures on a scale of 0.00 to 1.00, with higher values indicating a higher PaO_2, reflecting oxygenation reserve status in the mild hyperoxic range (PaO_2 of about 100–200 mmHg) [6]. ORi allows reflecting hyperoxemia by measuring the SpO_2 of venous blood as well as arterial blood [7]. Several studies have reported using this characteristic of ORi to detect hypoxemia earlier than pulse oximetry during rapid sequence induction of general anesthesia [8] as well as during one-lung ventilation [9]. In the twenty-first century, as the harms of hyperoxemia have been widely recognized, prevention of hypoxemia through pulse oximetry and hyperoxemia through ORi may become standard practice.

Evaluating ventilation is necessary even when using a pulse oximeter. Besides the gold standard capnometer, Radical-7® (Masimo) and NellcorTM PM1000N (Medtronic) among others are also available for assessing ventilation. These two devices can noninvasively and continuously monitor respiratory rate using sensors attached to the neck or fingertips [10, 11]. Modern anesthesiologists are expanding their activities, providing anesthesia management in intensive care units and non-operating room settings; thus, they need to understand the characteristics of these recently-developed respiratory monitoring devices to use them effectively in various situations.

Standard hemodynamic monitor in the future anesthetic management (Yoshifumi Kotake)

Current standard hemodynamic monitors continuously display electrocardiogram waveforms, plethysmogram from pulse oximetry, and arterial waveforms (if available). These waveforms may provide clinically relevant information with the aid of artificial intelligence and machine learning [12]. This has already been realized through the Hypotension Prediction Index [13]. The author of this section believes that other critical information, such as nociception and hemodynamic coherence, may be obtained and displayed in future hemodynamic monitors.

Intraoperative hypotension (IOH) has been reported to be associated with adverse outcomes. Hypovolemia, excessive vasodilation, and reduced ventricular function are considered the three major pathophysiological conditions of IOH, and are treated accordingly. In addition, excessive suppression of nociception, sympathetic nerve activity, adrenal function, and the renin-angiotensin-aldosterone axis may also contribute to IOH [14]. In this regard, objective assessment of nociception may serve as an important preventive measure to IOH-related morbidities [15, 16]. Currently, several modalities are available for nociception assessment using indices such as heart rate, heart rate variabilities, plethysmographic waveform and electrical skin conductance [17]. Most of the data used to calculate these indices can be obtained with the current hemodynamic monitors; therefore, integration to derive an index for nociceptive assessment is feasible.

Hemodynamic coherence is defined as concordance between macro and microcirculations, and regarded as a critical condition for successful resuscitation of hypovolemic and septic shock [18]. Both fluid resuscitation and vasopressors are typically used to optimize microcirculation, and adequate balance between fluid and vasopressors is necessary to re-establish hemodynamic coherence in critically ill patients and patients undergoing major surgeries. In this regard, assessment of microcirculation may be critically important. For this purpose, several parameters, such as assessments of capillary refill time and blood lactate, tissue oximetry, direct visualization of sublingual microcirculation, plethysmographic waveform and its amplitude may be used [19].

The time has come to choose neuromuscular monitor (Shunichi Takagi)

Monitoring guidelines for anesthesia management have been developed and updated in various countries. Of note, the American Society of Anesthesiologists has released Practice Guidelines for Monitoring and Antagonism of Neuromuscular Blockade [20], which state "When using quantitative monitoring, we recommend confirming a train-of-four ratio greater than or equal to 0.9 before extubation." Clinical trial results indicate that even sugammadex may not achieve adequate antagonism of muscle relaxation. Therefore, multimodal approaches, such as combined use of sugammadex and neuromuscular monitors for assessing neuromuscular transmission, may contribute to reducing residual neuromuscular blockade and thus potentially decrease the risk of postoperative respiratory complications. Enhancement of anesthesiologists' awareness using educational videos or introduction of alert systems would also be useful.

Neuromuscular monitors available in Japan have become increasingly diverse in recent years. Such monitors include: the AF-201P (Nihon Kohden, Tokyo, Japan), which can function both as a module and a stand-alone device; the TetraGraph (Senzime, Uppsala, Sweden, marketed by Fukuda Denshi in Japan), noted for its lightweight and compact design, developed by a U.S. anesthesiologist; the TwitchView (Blink Device Company, Seattle, WA, USA, marketed by Heiwa Bussan in Japan), which challenges traditional design norms, with a default pulse width of 300 μs (typically 200 μs) and a maximum stimulation current of 80 mA (typically 60 mA); and the ToFscan (idmed, Marseille, France, marketed by Century Medical in Japan), which employs a 3D acceleration sensor, is a hand adapter type for easy installation, and does not require calibration.

Electromyography type monitors are distinguished by the measurement site being either the hypothenar or interosseous muscles, both of which are solely innervated by the ulnar nerve. Anesthesiologists accustomed to traditional acceleromyograph monitors may need to pay special attention when using electromyography type monitors.

Therefore, anesthesiologists must become familiar with the features of any device they use, in order to ensure that they use them effectively.

What kind of integrated monitor is desired in the near future? (Kenichi Masui)

Information on anesthesia workstations has continued to increase over the years. An anesthesia workstation often consists of more than three monitors, such as a vital sign monitor, a monitor of ventilation through an anesthesia machine, a monitor for an anesthesia information management system, and monitors on syringe pumps. Additionally, every monitor shows many numbers and waves. With increased information available, it can become challenging to focus on every change in numbers and waveforms on the monitors, leading to the possibility of anesthesiologists only monitoring information when alarms are sounding.

The ways in which a monitor screen can be made easier to recognize are as follows:(1) Reducing the amount of information displayed; (2) highlighting important information; and (3) customizing the screen layout. However, reduction of information seems to be inappropriate. For example, the waveforms for peripheral SpO_2 and partial pressure of carbon dioxide cannot be omitted because reliability of their values would be compromised. Highlighting such as a blinking feature for abnormal values has already been implemented. Customization of the screen layout is possible on each monitor, although it is limited. Although the visibility of each individual monitor screen is well-considered, it becomes poor when multiple monitors are used simultaneously.

Drastic customization may work to improve the readability of screen displays and may be suitable for a future integrated anesthesia monitor. Currently, respiratory-related information is displayed separately on multiple monitors, including SpO_2, end tidal carbon dioxide, partial pressure of inspired and expired oxygen, and mechanical ventilation-related information (e.g., tidal volume and peak inspiratory pressure). These pieces of information are essential for daily anesthesia management, regardless of the patient's general condition. Anesthesiologists typically perform a wide range of interventions, including drug administration, artificial ventilation, fluid (and blood) infusion, and body temperature management. Therefore, there is a need to integrate the information displayed separately, as previously mentioned.

Continuously monitoring multiple screens during anesthesia management can be stressful for anesthesiologists, who must respond immediately to sudden changes in a patient condition during surgery with great effort and concentration. A well-organized integrated "single-screen" monitor should be developed and introduced in the near future.

Conclusion

In this symposium, we discussed the current evidence on relatively new monitoring devices and indices and their future prospects. We believe that these insights will be beneficial for the daily management of clinical anesthesia.

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Declarations

Conflict of interest Shinju Obara is an Editor of Journal of Anesthesia, and an Editorial board of JA Clinical Reports. Naoyuki Hirata is an Editor of Journal of Anesthesia, and an Editorial board of JA Clinical Reports. Kenichi Masui had received payments for delivering domestic lectures from Masimo Japan Corporation (Tokyo, Japan), Covidien Japan Inc. (Tokyo, Japan), and MSD K.K. (Tokyo, Japan), and is an Editor of Journal of Anesthesia, and an Editorial board of JA Clinical Reports.

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