Do the Monitoring of the Depth of Anesthesia and Neuromuscular Monitoring Have an Impact on the Quality of Recovery After General Anesthesia?

Katarina Atlagić[1], Nataša Kovač[1], Tomislav Radočaj[1,2], Sabina Babić[1] and Nikolina Vratan[1]

[1] Department of Anesthesiology, Intensive Care and Pain Therapy, Sestre milosrdnice University Hospital Center, Zagreb, Croatia;
[2] School of Medicine, University of Zagreb, Zagreb, Croatia

CORRESPONDING AUTHOR Katarina Atlagić, Department of Anesthesiology, Intensive Care and Pain Therapy, Sestre milosrdnice University Hospital Center, Zagreb, Croatia
katarina.atlagic@gmail.com

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SUMMARY

Postoperative recovery quality is a critical indicator of patient outcomes. Traditional assessments focus on vital signs, mobility, pain, and nausea, while modern approaches include muscle strength, emotional state, physical independence, and patient-reported well-being. This study aimed to compare the overall quality of recovery following general anesthesia after major abdominal operations guided by advanced monitoring — bispectral index (BIS) and train-of-four (TOF) — with clinical sign–based anesthesia.

This prospective observational study involved 50 patients undergoing elective surgeries lasting at least 2 hours. Participants were randomized into two groups: Group A (experimental) with BIS and TOF monitoring, and Group B (control) with clinical sign-based monitoring. Recovery quality was assessed using the Quality of Recovery-40 (QoR-40) questionnaire and a JAMAR® dynamometer for grip strength.

No significant differences were found between the groups in recovery quality scores. However, Group A exhibited more stable hemodynamics and faster extubation times. A significant decrease in grip strength was observed in men, particularly in Group A.

Advanced monitoring during general anesthesia may enhance hemodynamic stability and reduce recovery time. Further studies are needed to explore its impact on long-term recovery outcomes.

KEYWORDS

General anesthesia; Bispectral index; Train-of-four; Recovery quality; Muscle strength; QoR-40 questionnaire

Introduction

The quality of recovery after general anesthesia is a key indicator of postoperative outcomes and patient safety. Traditionally, recovery assessment has focused on cardiorespiratory stability, basic mobility, pain, and nausea. However, modern perioperative medicine recognizes that recovery extends beyond physiological parameters to include emotional well-being, physical independence, and the patient's subjective experience[1,2]. Despite this broader understanding, there is still no universal definition or standardized tool for evaluating postoperative recovery quality.

One of the most widely accepted instruments is the Quality of Recovery-40 (QoR-40) questionnaire, which evaluates five domains of recovery: physical comfort, emotional state, physical independence, psychological support, and pain[1,3]. The QoR-40 provides a structured and patient-centered measure of recovery and has been translated and validated in multiple languages, including Croatian, ensuring cultural and linguistic applicability[3].

The depth of anesthesia and adequacy of neuromuscular blockade are critical factors influencing both intraoperative safety and postoperative recovery. Advanced monitoring technologies, such as the bispectral index (BIS) and train-of-four (TOF), allow for a more precise control of anesthetic depth and neuromuscular function. The bispectral index analyzes electroencephalographic (EEG) signals to quantify anesthetic depth, enabling tailored drug administration and reducing the risk of intraoperative awareness[4]. The TOF method applies four electrical stimuli to assess neuromuscular transmission and the degree of muscle relaxation, facilitating a safer timing of extubation and reversal of blockade[5]. These technologies support a more individualized approach to anesthesia management and may reduce postoperative complications, particularly those related to residual muscle weakness or hemodynamic instability[6,7].

Despite these technological advances, the extent to which improved intraoperative monitoring translates into better patient-centered recovery outcomes remains insufficiently explored.

In this study, we compared the quality of recovery following general anesthesia guided by BIS and TOF monitoring with anesthesia guided solely by clinical signs. Recovery was assessed using patient-reported outcomes and objective measures of muscle strength.

Materials and methods

This prospective, randomized, controlled trial was conducted between May 2024 and February 2025 at Sestre milosrdnice University Hospital Center in Zagreb, Croatia. The aim of the study was to compare the quality of recovery following extubation between two groups of patients undergoing general anesthesia. The experimental group (Group A) was managed using advanced neuromonitoring, including BIS and TOF, while the control group (Group B) was monitored using standard clinical parameters[8].

A total of 50 adult patients scheduled for elective surgical procedures with an expected duration of at least 2 hours were enrolled. Patients undergoing emergency surgery or procedures of a shorter duration were excluded. Participants were randomly assigned to one of the two groups using a sealed-envelope randomization method. All patients provided a written informed consent prior to inclusion. The study protocol was approved by the Ethics Committee of Sestre milosrdnice University Hospital Center.

The sample size was calculated based on the primary outcome: the QoR-40 total score at 24 hours postoperatively. A difference of 10 points between the groups was considered clinically significant, based on previous validation studies. Assuming a

standard deviation of 12 points, a two-sided α level of 0.05, and a power (1−β) of 80%, a minimum of 23 patients per group was required. To compensate for potential dropouts, the sample size was increased to 25 patients per group.

Anesthesia induction was standardized in both groups using propofol, sufentanil, and rocuronium, while maintenance was achieved with sevoflurane. Standard intraoperative monitoring was applied in both groups. In addition, patients in Group A were monitored using BIS and TOF.

In the experimental group, extubation criteria were predefined as BIS > 70, TOF ratio ≥ 0.9, and end-tidal sevoflurane concentration corresponding to a minimum alveolar concentration (MAC) of < 0.1. Neuromuscular blockade was reversed using neostigmine and atropine according to TOF-guided assessment. In the control group, decisions regarding neuromuscular blockade reversal and extubation were based solely on clinical assessment by the attending anesthesiologist, without the use of quantitative neuromuscular monitoring.

Hemodynamic parameters (heart rate, systolic and diastolic blood pressure, and peripheral oxygen saturation) were recorded at induction and extubation. The total intraoperative dose of rocuronium was documented. Due to an unequal sex distribution between the groups, a subgroup analysis of muscle strength by sex was performed. The internal consistency of QoR-40 domains was assessed using Cronbach's alpha.

Muscle strength was assessed using a JAMAR® hand dynamometer (Performance Health Holdings, Inc., Warrenville, Illinois, USA) preoperatively and 24 hours postoperatively[9]. The primary outcome was the quality of postoperative recovery, measured 24 hours after surgery using the Croatian version of the QoR-40 questionnaire[1,3]. Secondary outcomes included postoperative muscle strength and the incidence of residual neuromuscular weakness.

The QoR-40 questionnaire consists of 40 items rated on a five-point Likert scale (1–5), yielding a total score ranging from 40 to 200, with higher scores indicating better recovery. The Croatian version has been previously translated, culturally adapted, and validated[3].

Statistical analysis was performed using R version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were tested for normality and presented as a mean ± standard deviation or a median (interquartile range, IQR), as appropriate[10]. Between-group comparisons were conducted using the independent samples t-test or Mann–Whitney's U test. Categorical variables were analyzed using the chi-square test or Fisher's exact test. A P value of < 0.05 was considered statistically significant.

Results

The study included 50 participants, ages 37–86, physical status classification system (ASA) 1–3, with 46% women and 54% men. The average BMI was 27, and the average operation time was 3 hours and 20 minutes. In this study, the patients were divided equally into the control and experimental group (25 each). The control group had standard monitoring (ECG, blood pressure, pulse oximetry, capnography), while the experimental group used additional BIS and TOF indices during extubation.

Socio-demographic and clinical parameters showed no significant differences between groups in age, body weight, BMI, duration of anesthesia, or total dose of muscle relaxant ($P > 0.05$). The only statistically significant difference was in sex distribution ($P < 0.001$), with a higher proportion of women in the experimental group. Blood pressure showed a significant increase in systolic and diastolic pressure at extubation compared to induction ($P < 0.05$). Systolic pressure was significantly lower in the experimental group at extubation, indicating better hemodynamic stability in that group. Diastolic pressure showed no significant differences

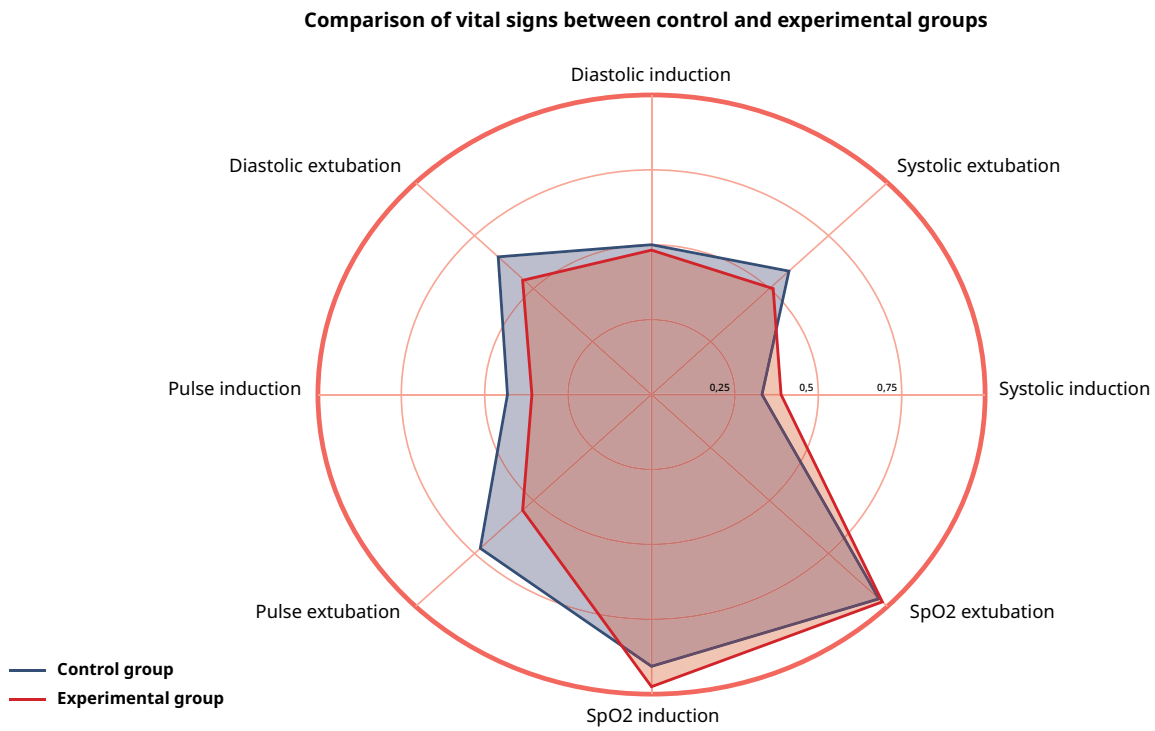


FIGURE 1. The comparison of vital sings between the control and experimental group

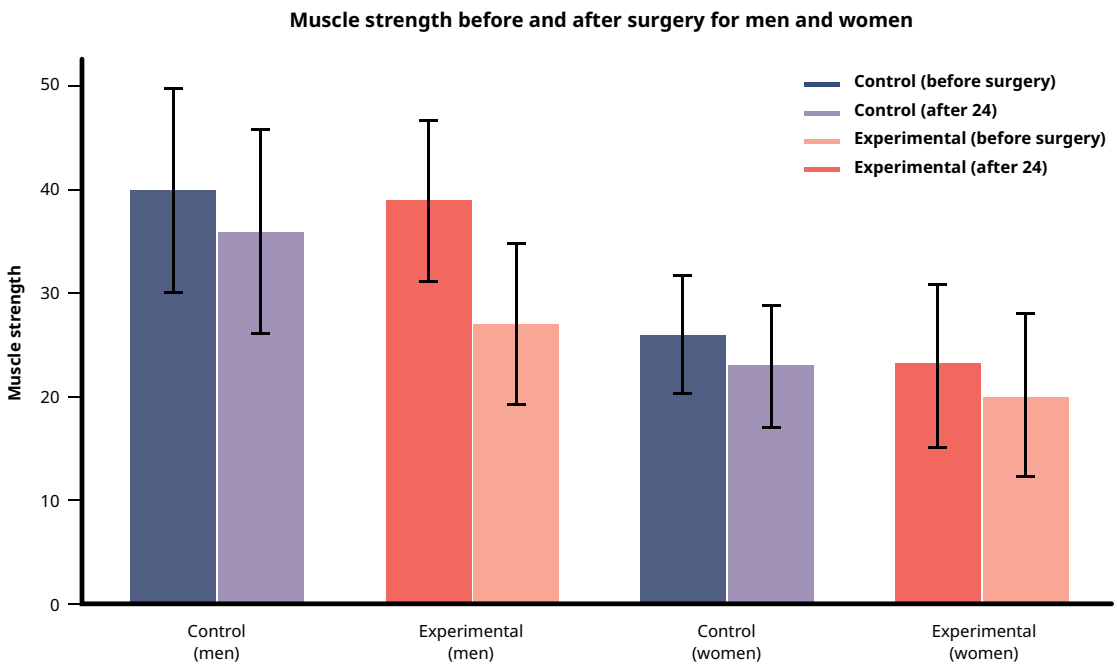


FIGURE 2. The results of grip strength measurements

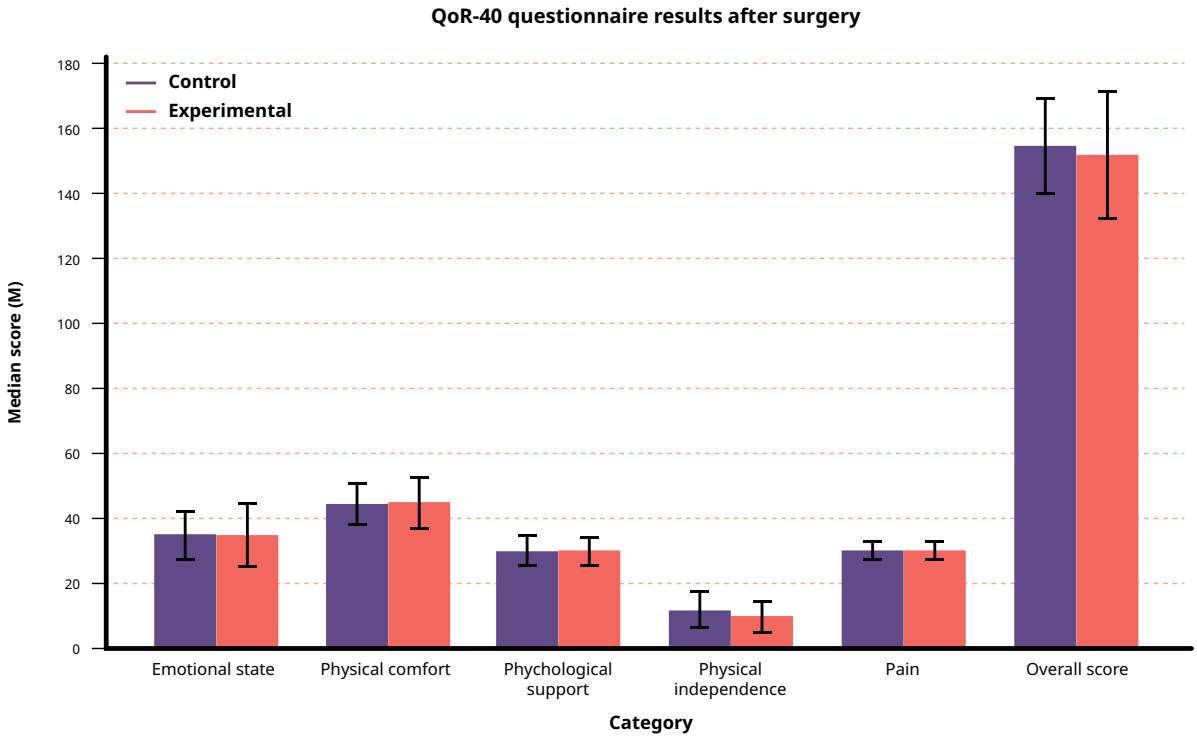


Figure 3. Responses to the QoR-40 questionnaire and figure

between groups ($P = 0.373$). Heart rate was significantly lower in the experimental group ($P = 0.008$), and in both groups it significantly increased at extubation ($P < 0.001$). Oxygen saturation showed no significant differences between groups, or between induction and extubation measurements ($P > 0.05$) (Figure 1). Muscle strength was analyzed separately by sex due to an uneven distribution. In men, a significant decrease in muscle strength was observed after surgery ($P < 0.001$), with a more pronounced decline in the experimental group (Figure 2). In women, no significant changes in muscle strength were noted ($P > 0.05$). The quality of recovery (QoR-40 questionnaire) showed no statistically significant differences between the groups in terms of emotional state, physical comfort, psychological support, physical independence, or pain (Figure 3). The pain domain had low internal consistency, indicating the need for a cautious interpretation of results in that domain.

Discussion

The results of this study indicated that the use of advanced BIS and TOF monitoring may have a positive effect on intraoperative and postoperative stability in patients under general anesthesia. The experimental group showed more stable systolic blood pressure values and a lower heart rate at extubation, suggesting a reduced stress response compared to the control group. Such hemodynamic stability is important to reduce the risk of complications and may contribute to a higher quality and faster postoperative recovery, as well as a reduced need for additional analgesics or sedatives[1,2,9]. Although a statistically significant sex distribution imbalance was observed with more women in the experimental and more men in the control group, other baseline characteristics (age, BMI, anesthesia duration, total muscle relaxant

dose) were comparable. This indicates good sample balance in most variables, increasing the reliability of the results.

Regarding the subjective experience of recovery, the QoR-40 questionnaire did not show statistically significant differences between the groups in any of the five domains (pain, physical independence, physical comfort, emotional state, psychological support). This suggests that advanced monitoring did not significantly affect the patients' subjective perception of recovery within 24 hours postoperatively. However, our results suggest a somewhat faster regaining of consciousness and shorter stay in the post-anesthesia care unit in the experimental group, possibly due to more precise anesthesia depth management[4,9].

Similar findings are reported in the literature. Avidan et al.[11] showed that using BIS can shorten awakening time from anesthesia and reduce postoperative complication rates. Leslie and Short highlighted that maintaining an appropriate depth of anesthesia is a key component of anesthetic management, as both excessive and insufficient anesthesia may be associated with adverse outcomes[12]. Train-of-four allows for more precise neuromuscular recovery assessment and may reduce the risk of residual muscle weakness, confirmed by Saldanha[13]. An interesting finding was the difference in postoperative muscle strength decline among men, which was greater in the experimental group, while this difference was not statistically significant in women. This result raises the question of potential sex-based differences in physiological response to anesthesia, as proposed by Buchanan et al.[14], although Jaensson et al.[15] did not find such effects. Further research is needed to clarify the clinical implications of these differences.

Although the QoR-40 questionnaire did not detect differences between the groups, it may be too broad to capture the subtle effects of advanced monitoring in the early recovery phase. Especially in the pain domain, where variation was minimal, the questionnaire might lack sensitivity to detect short term differences[3].

The application of BIS and TOF monitoring was associated with better intraoperative stability and faster initial recovery, though it did not significantly affect subjective feelings of recovery per the QoR-40[3,7,16]. The results support introducing advanced monitoring into routine clinical practice, especially for longer procedures.

This study had several limitations, including a relatively small sample size, its single-center design, and the inability to blind the attending anesthesiologist, which may have introduced performance bias. Additionally, neuromuscular recovery in the control group was assessed clinically, reflecting routine practice but potentially introducing variability. While BIS is widely used in clinical practice, it represents a derived index and may not capture the full complexity of cortical dynamics during emergence, potentially limiting the precision of anesthetic depth assessment.

Future studies should include larger samples, additional muscle function measures, and long-term outcomes to more comprehensively assess these technologies' contributions to perioperative care.

Conclusion

While advanced monitoring improves physiological stability during extubation, its effect on overall recovery remains uncertain. Further larger-scale studies are needed to clarify its clinical relevance. ■

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SAŽETAK

Utječu li monitoring dubine anestezije i neuromuskularni monitoring na kvalitetu oporavka nakon opće anestezije?

Katarina Atlagić, Nataša Kovač, Tomislav Radočaj, Sabina Babić i Nikolina Vratan

Kvaliteta postoperativnog oporavka ključan je pokazatelj ishoda za pacijente. Tradicionalne procjene usredotočuju se na vitalne znakove, pokretljivost, bol i mučninu, dok moderni pristupi uključuju mišićnu snagu, emocionalno stanje, fizičku neovisnost i samoprocjenu pacijenta. Cilj ovog istraživanja bio je usporediti ukupnu kvalitetu oporavka nakon opće anestezije kod velikih abdominalnih operacija vođenih naprednim tehnikama monitoringa – bispektralnim indeksom (BIS) i nizom četiri stimulacije (TOF) – u odnosu na konvencionalno kliničko praćenje.

Provedeno je prospektivno opservacijsko istraživanje na 50 pacijenata podvrgnutih elektivnim operacijama u trajanju od najmanje dva sata. Sudionici su nasumično raspoređeni u dvije skupine: skupinu A (eksperimentalna) s BIS i TOF monitoringom i skupinu B (kontrolna) s kliničkim praćenjem. Kvaliteta oporavka procijenjena je pomoću upitnika QoR-40 i dinamometra JAMAR® za mjerenje stiska šake.

Nisu pronađene značajne razlike u rezultatima kvalitete oporavka između skupina. Skupina A pokazala je stabilnije hemodinamske parametre i brže vrijeme ekstubacije. Značajan pad snage stiska šake uočen je kod muškaraca, a osobito u skupini A.

Napredni monitoring tijekom opće anestezije može poboljšati hemodinamiku i skratiti vrijeme oporavka. Potrebna su daljnja istraživanja za procjenu utjecaja na dugoročne ishode oporavka.

KLJUČNE RIJEČI

Opća anestezija; Bispektralni indeks; Neuromišićni monitoring; Kvaliteta oporavka; Mišićna snaga; QoR-40 upitnik