Original Article

Does the objective measurement of muscle strength improve the detection of postoperative residual muscle weakness?

Durga Padmaja, Geetha Singam, Rabbani Tappa, Krishnarao Maremanda, Nitesh Kabra, Anupama Barada[1]

Department of Anaesthesiology and Intensive Care, Nizam's Institute of Medical Sciences, Hyderabad, Telangana, India, [1]Medical Student and Research Assistant, China Medical University, Shenyang, China

Abstract

Background and Aims: The postoperative residual neuromuscular block (PRNB) has a significant impact on patient safety and well-being, but continues to remain underestimated. Objective evaluation of handgrip strength using a force dynamometer can be useful to identify postoperative muscle weakness.

Material and Methods: Thirty-two American Society of Anesthesiologists (ASA) class I and II patients who received general anesthesia were included. Patients were extubated after the train-of-four (TOR) ratio (TOFR) was >0.90 and the clinical criteria for motor power recovery were judged as adequate. The measurements of handgrip strength and peak expiratory flow rate (PEFR) were obtained at baseline, 15 min after extubation, and 1, 2, and 4 h postoperatively. The incidence of significant decline from baseline (>25%) was determined. The correlation between handgrip strength and PEFR was assessed using Spearman correlation. The time to return to baseline for muscle grip strength and PEFR was performed using Kaplan–Meier survival analysis. A *P* value of 0.05 was considered significant for all tests.

Results: The incidence of the significant decline in handgrip strength from baseline was 100% at 15 and 60 min, 76% at 2 h, and 9.4% at 4 h. There was a strong correlation between muscle grip strength and PEFR (0.89, $P < 0.001$). None of the patients exhibited the potential complications of PRNB. (PRMB in abstract. It should be uniform) The mean time to return to the baseline value of muscle grip strength was 3.8 h (95% confidence interval [CI] 3.6–3.9), and the mean time to return to baseline for PEFR was 3.2 h (95% CI 2.9–3.4 h).

Conclusion: Objective assessment of muscle grip strength using a force dynamometer has the potential to be a new objective metric to monitor postoperative muscle weakness.

Keywords: Extubation, force dynamometer, handgrip strength, objective, peak expiratory flow rate, train of four

Introduction

Postoperative residual neuromuscular block continues to be a significant postoperative complication despite improvements in the molecules used for neuromuscular blockade. About 10%–40% of patients experience postoperative residual weakness, but it remains largely unrecognized.[1] There has been a significant emphasis on perioperative quantitative neuromuscular monitoring to ensure a train-of-four (TOF) ratio (TOFR) greater than 0.9 before extubation.[2,3] The accepted standard definition for adequate recovery from the neuromuscular block, the TOFR of ≥0.9, is believed to restore the functional integrity of the muscles involved in airway protection.[3,4] However, even after achieving a

Address for correspondence: Dr. Geetha Singam, Department of Anaesthesiology and Intensive Care, Nizam's Institute of Medical Sciences, Hyderabad – 500 082, Telangana, India.
E-mail: singamgeetha11@gmail.com

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TOFR of >0.9, there is a possibility of a neuromuscular block,[5] which is not detected by TOF monitoring but can have a significant impact on postoperative respiratory function, airway responses, and also the well-being of patients. The impairment of postoperative muscle strength remains frequently underestimated because the clinical signs of postoperative residual neuromuscular block (PRNB)(PRNB)) are not necessarily evident. A prospective cohort study was undertaken in patients receiving neuromuscular blocking drugs to evaluate the role of a force dynamometer in identifying postoperative residual muscle weakness. The primary objective of the study was to assess the postoperative residual muscle weakness by using a force dynamometer in patients with adequate reversal of the neuromuscular block to achieve complete recovery of TOF by comparing the immediate postoperative muscle strength to the preoperative baseline value. The secondary objectives were to determine the time to recovery to baseline muscle strength and correlate the muscle strength changes with respiratory function using peak expiratory flow rate (PEFR).

Material and Methods

Ethical committee approval was obtained for the study; also, informed consent was obtained from all patients recruited for the study. Sample size was estimated using Gpower (version 3)[6] based on the data from the pilot study conducted on 10 subjects. For a mean preoperative handgrip strength of 32 kg and a standard deviation (SD) of 6 and postoperative grip strength of 29 kg with an SD of 5, the sample size required to detect this change (effect size calculated was 0.56) with an alpha error of 0.05 and power of 80% was 27. We included 32 adult patients scheduled for laparoscopic cholecystectomy under general anesthesia in this prospective observational study. Premedication and general anesthesia were administered according to the institutional standard operating procedures (SOP). Primary outcomes were defined as a significant reduction in the postoperative muscle power by greater than 25%, and the secondary outcome was the impact of these factors on postoperative PEFR.

The following were the inclusion criteria: age ≥18 years and <60 years and American Society of Anesthesiologists (ASA) functional class I–III. Patients with a body mass index (BMI) of <18 and >35; patients with disorders likely to influence the motor power or neuromuscular blocking drugs, such as preexisting neuromuscular disorders, respiratory disorders, renal and hepatic dysfunction, and electrolyte imbalance; and patients with significant pain or disability precluding testing of preoperative PEFR were excluded from the study. Patients who were unable to comprehend the testing or unable to perform the test due to pain, oral ulcers, and facial muscle weakness were excluded from the study. The post-inclusion–exclusion criteria were subjects requiring conversion to general anesthesia, patients who had considerable pain (Visual Analog Scale [VAS] >5), Ramsey Sedation Scale (RSS) >2, patients with postoperative delirium, or patients requiring postoperative ventilation.

All the patients included in the study had preoperative baseline muscle power of the dominant hand quantified using a force dynamometer (Camray EH 101; Camry Scale South El Monte, USA) and PEFR estimated using a peak flow meter (Breathe O meter; Cipla Ltd, Mumbai, India) after thorough demonstration of the methods along with the routine preoperative evaluation. The best of three attempts of the handgrip force and PEFR were registered. Intravenous (IV) cannulation was performed on the nondominant hand. Patients requiring cannulation of the dominant hand whose power was tested preoperatively were excluded from the study.

General anesthesia was induced using fentanyl citrate 2 μg kg^{-1} and propofol 1.5–2.5 mg kg^{-1}, and rocuronium 0.6 mg kg^{-1} ideal body weight was given for tracheal intubation. Pressure-controlled ventilation with a maximum peak pressure of 30 cmH_2O to achieve tidal volumes of 4–6 ml kg^{-1} and positive end-expiratory pressure of 5–8 cmH_2O was used during anesthesia maintenance. Ventilation was adjusted to maintain an end-tidal CO_2 of 35 mmHg. FiO_2 of 0.5 was used during maintenance and 1.0 before extubation. General anesthesia was maintained by sevoflurane (0.5–2 Vol%) or propofol (6–12 mg kg^{-1}) infusion and intermittent bolus application of fentanyl 0.5 μg kg^{-1} to maintain state entropy within a range of 40–60 and surgical pleth index (SPI using plethysmograph on the carescape Monitor B850; GE Healthcare, Helsinki Finland) at <50. Intraoperatively, the TOFR was monitored using TOF-Watch™ (Organon Teknika), and a bolus of 0.2 mg kg^{-1} of atracurium besylate was administered to maintain two to three twitches of TOF. No additional atracurium was administered 15 min before completion of the procedure. All patients received dexamethasone 4 mg IV after induction and ondansetron 4 mg IV 15 min before extubation as prophylaxis against postoperative nausea and vomiting. All patients received forced air warming during the surgery. The neuromuscular block was reversed with neostigmine 0.08 mg kg^{-1}, and glycopyrrolate 0.02 mg kg^{-1} was administered along with it. TOFR >0.90 was ensured before extubation by a research team member. Patients were extubated after they were fully awake, alert, and breathed spontaneously. The clinical criteria for motor power recovery were assessed in all patients, and they were shifted to the postanesthesia care unit (PACU) when their handgrip was judged as adequate, ability to lift and sustain head lift was present, and the TOFR was >0.95. In the

PACU, they were nursed in the head-up position and oxygen 1–6 L min^{-1} was administered by face mask to maintain an oxygen saturation (SpO_2) value of >95%. VAS and RSS scores were evaluated at 15-min intervals. Whenever the VAS exceeded 4, fentanyl IV was given by the PACU nurses. Patients who had a postoperative body temperature <36°C during the PACU stay were excluded from the study. The Fast Track score[7] [Appendix 1] was monitored, and patients with a Fast Track score <10 at 30 min after extubation were excluded from the study.

In the PACU, handgrip strength and PEFR were measured by a single nurse trained by the investigator to perform the test. The first postoperative testing was performed 15 min after extubation or as soon as the patient was alert and cooperative with a Fast Track score >10 (T0). The measurements were repeated in the PACU at 1 h (T1) after PACU arrival and 2 h (T2) and 4 h (T4) postoperatively. The time to sit and stand without support was noted. The occurrence of major respiratory complications such as desaturation, SpO_2, respiratory depression, airway obstruction, and pulmonary aspiration was noted.

Statistical analysis

Postoperative PEFR and muscle power were analyzed as mean and SD and percentages of baseline. The significance of the change from baseline was analyzed using analysis of variance (ANOVA) for repeated measures and Dunnet post hoc analysis. A two-tailed P value of <0.05 was considered a significant change. A change of >25% was used to dichotomize the continuous data, and the incidence of significant reduction was determined. The correlation between TOF% and muscle strength and PEFR was assessed using Spearman correlation. A correlation coefficient of >0.5 was considered a significant correlation. Kaplan–Meier survival analysis was performed to determine the time to return to 75% of baseline for muscle grip strength and PEFR. A P value of > 0.05 was considered significant for all the statistical tests.

Results

Forty patients were screened for the study based on their basic biometric and specific perioperative anesthesia-related assessment. Three patients were excluded due to poor comprehension of the study procedure. Five patients were excluded after initial inclusion due to unanticipated conversion to open surgical procedure, postoperative VAS >5, Fast Track score <10, hypothermia even at 30 min after extubation, and postoperative delirium. Data from 32 patients were analyzed.

Table 1 presents the demographic data of the participants. All patients whose data were analyzed had TOF >90 at extubation and >0.95 at 15 min after extubation, fulfilled the clinical criteria for motor recovery, and had a complete recovery from general anesthesia (Fast Track score >10). The handgrip strength assessed using the force dynamometer was significantly low [Figure 1a]. The mean percentage change from baseline for handgrip strength and PEFR and the number of patients with more than 25% reduction in handgrip strength are shown in Table 2. All the patients at 15 and 60 min and 76% of the patients at 2 h after arrival to the PACU had a reduction of more than 25% of baseline. The motor grip returned to >75% of baseline by 4 h in all patients [Table 2]. There was a significant decline in PEFR from baseline [Figure 1b]. None of the patients exhibited the potential complications of PRNB (Postop residual neuromuscular blockade) in terms of muscle impairment resulting in an upper airway collapse and desaturation. All except two patients had their muscle grip strength return to baseline by 4 h. The mean time to return to the baseline value of muscle grip strength was 3.8 h (95% confidence interval [CI] 3.6–3.9) [Figure 2a] and yes 3.2 h (95% CI 2.9–3.4 h) for PEFR [Figure 2b]. Patients were able to sit without support for about 1 h after extubation and stand without support for about 6 h after extubation [Table 1]. There was a strong correlation between muscle grip strength and PEFR (correlation coefficient 0.86, $P < 0.001$) [Figure 3]. None of the patients had complications such as upper airway collapse, desaturation, respiratory impairment, or reintubation.

Table 1: Demographic and perioperative data

Parameter	Mean (SD)
Age (years)	38.8 (8.7)
Weight (kg)	60.5 (6.7)
Height	159.3 (9.3)
BMI	23.8 (2.5)
Duration of anesthesia (min)	128.2 (27.2)
TOFR at 15 min after extubation	0.98 (0.028)
Time to sit without support (min)	57.0 (11.8)
Time to stand without support (min)	249.3 (40.9)

BMI=Body mass index, SD=Standard deviation, TOFR=Train-of-four ratio

Discussion

The results of this study showed that there was a significant decline in handgrip strength even in patients who exhibited clinical recovery of muscle strength and TOFR. There was a significant correlation between reduction in muscle strength and reduction of PEFR. Neuromuscular blocking agents (NMBAs) are frequently used in the intraoperative setting, but their use can be associated with the postoperative PRNB(Postop residual neuromuscular blockade).[8,9] It can occur even with a single dose of NMBA and also with an

Table 2: Changes in the muscle grip strength and PEFR

Time	Muscle grip strength		PEFR	
	% Change from baseline, mean % change (SD)	% of patients with muscle strength Muscle strength of <25% of baseline	% Change from baseline, mean % change (SD)	% of patients with PEFR of <25% of baseline
Postop 15 min (T0)	35.2 (3.3)	100	33.4 (3.2)	100
Postop 1 h (T1)	30.9 (2.3)	100	28.8 (4.6)	81.4
Postop 2 h (T2)	27.2 (2.4)	78.1	23.0 (4.4)	34.4
Postop 4 h (T4)	19.0 (13.7)	9.4	10.4 (3.7)	6.2

PEFR=Peak expiratory flow rate, SD=Standard deviation

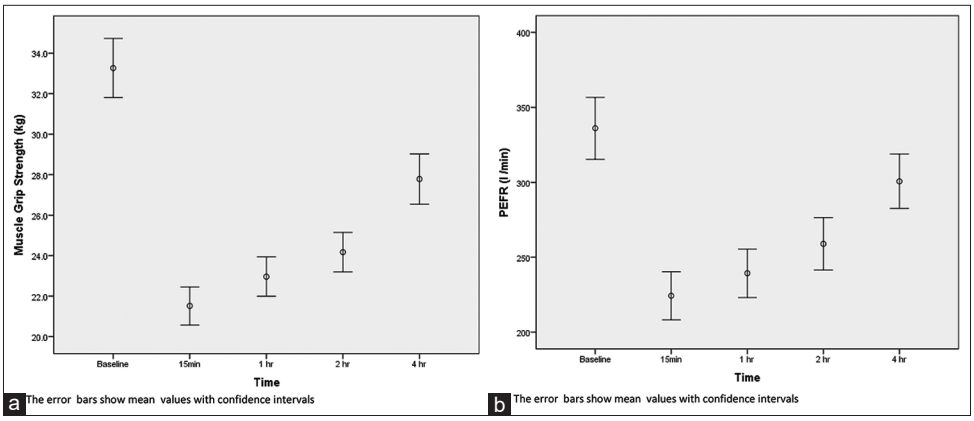

Figure 1: (a) Changes in the muscle grip strength in the postoperative period. (b) Changes in PEFR in the postoperative period. PEFR = peak expiratory flow rate

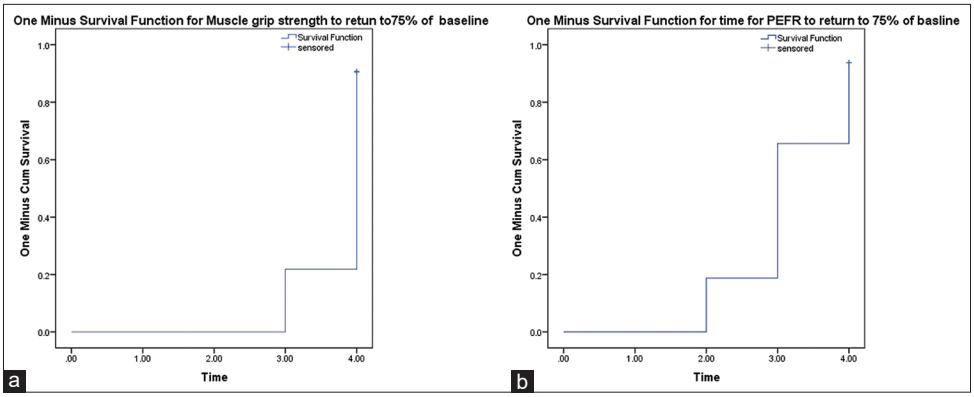

Figure 2: (a) Kaplan–Meier analysis for muscle grip strength. (b) Kaplan–Meier analysis for PEFR. PEFR = peak expiratory flow rate

intermediate duration of anesthesia.[10,11] Postoperative residual weakness is a significant patient safety threat and an essential factor to monitor and modify, especially in the era of Enhanced Recovery After Surgery (ERAS). A large multicenter study showed that even when patients were clinically judged to be suitable for extubation, 65% of patients were found to have a TOFR of <0.9, and a TOFR of <0.6 was seen in 31% of patients.[8] Residual drug-induced muscle weakness in the postoperative period is associated with adverse patient events that may include unplanned tracheal reintubation in the PACU, delayed discharge from the PACU, aspiration, pneumonia, hypoxemia, and hypoventilation.[9,12,13] The clinical relevance of postoperative muscle strength impairment is understood well, but often underestimated because the clinical signs of RNMB are not necessarily evident.

There has been a considerable emphasis on the use of perioperative quantitative neuromuscular monitoring, in particular, acceleromyography. It is widely accepted that a quantitative measurement of TOFR and recovery of TOFR to ≥0.9 is sufficient neuromuscular recovery for extubation.[8,14] But this gold standard of TOF may not be able to detect lesser degrees of PRNB (Postop residual neuromuscular blockade).[15] It is known that TOF begins to recover when 10% of the receptors are free of neuromuscular blocking drug and returns to normal when about 30% of the

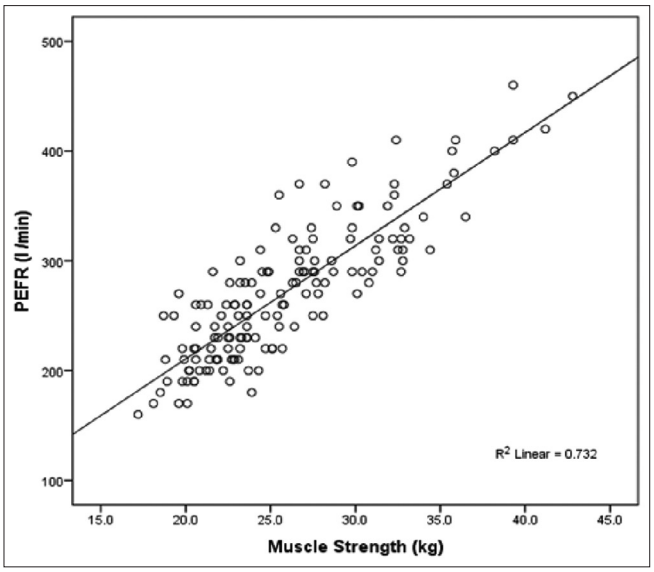

Figure 3: Correlation between muscle grip strength and PEFR. PEFR = peak expiratory flow rate

receptors recover from the competitive block of acetylcholine receptors.[16] Thus, there can be significant inhibition of receptors and PRNB Please use the uniform abbreviation that cannot be excluded by monitoring TOFR.[5] Another reason for the failure to detect RNMB Please use the uniform abbreviation is using acceleromyographic TOF for monitoring. There is a discrepancy between mechanomyographic and acceleromyographic TOF. For a mechanomyographic TOF of 0.9, the corresponding acceleromyographic TOF was 0.95. To identify residual neuromuscular weakness, the negative predictive values for acceleromyographic TOFs of 0.9, 0.95, and 1.0 were 37%, 70%, and 97%, respectively.[15] Clinical signs such as head lift and handgrip are insensitive indicators of the residual block.[14,17] Hence, it is crucial to identify the reduction of muscle strength using objective measures.

Handgrip strength can be measured using a force dynamometer. Using a force dynamometer, we demonstrated a significant reduction in muscle grip strength in patients who had no clinical signs of neuromuscular weakness, and it was considered to be adequately reversed using accelerometry with TOF >0.95. Only a few studies have used a dynamometer to quantify muscle strength as a metric for residual neuromuscular paralysis in the PACUs.[5,18,19] During recovery from neuromuscular blockade, there was a significant correlation between muscle grip strength and TOFR.[19] The SOP for early mobilization and improved overall outcome in ERAS protocols include maintenance of safety standards and use of neuromuscular monitoring. The use of these protocols has been shown to facilitate rapid recovery of muscular power and reduce perioperative complications.[20] Although we have maintained these safety standards of using neuromuscular monitoring and ensuring a TOFR ≥0.9 before extubation and a TOFR of 1 after extubation and in the PACU, our data show that there was a significant reduction of postoperative muscle power when measured using force dynamometer. There was a considerable muscle grip strength reduction from preoperative value even in patients with a Fast Track score of >12. The decline in muscle strength was not detected by TOFR, clinical examination, or the Fast Track score in the PACU. This study indicates that the Fast Track score or TOFR is inadequate to identify minor degrees of postoperative muscle weakness.

Studies have demonstrated a significant association between grip strength and pulmonary function in patients with stroke[21] or diabetes,[22] and it has also been used as a metric for nutritional status.[23] In this study, there was a significant reduction in the postoperative PEFR, although SpO_2, respiration, and airway patency and reflexes remained unaffected. There was a significant correlation between muscle grip strength and PEFR. The decline in the PEFR corresponded to a reduction in muscle grip strength from baseline. None of the patients exhibited any potential complications of muscle power impairment, such as upper airway collapse, desaturation, respiratory impairment, or reintubation, though there was a significant reduction in PEFR. The other consequences of residual weakness are unpleasant symptoms that can interfere with early mobilization. There was a significant relationship between the subjective signs of weakness and residual neuromuscular block.[24] There was a delay in the postoperative ability to sit up by about 1 h and stand up by 4.5 h in this study. These are essential metrics for daycare surgeries where early discharge is contemplated. However, this motor wea kness has not been shown to improve with additional administration of reversal agents.[5] It is difficult to comment on whether reduction in the muscle strength is related to neuromuscular transmission or other patient-related factors that can also influence postoperative muscle strength.[25]

The results of this study suggest that routine use of simple objective measurement of muscle grip strength using a force dynamometer can readily identify postoperative residual muscle weakness. Early identification of postoperative residual muscle weakness and prevention of its complications are crucial in patient safety. This study emphasizes the need for the inclusion of objective postoperative muscle power testing as a criterion in the ERAS protocol and targets the anesthetic management toward early recovery of muscle strength. It is essential to use this as a criterion for discharge in daycare surgeries. The force dynamometer is an accessible, simple, and inexpensive equipment. Its use reduces the subjectivity in identifying PRNB (Postop residual neuromuscular blockade). Please

check the abbreviation The testing is not painful, unlike TOF, and can be performed and interpreted by the nursing staff in the PACU with minimal training. Objective measurement of muscle grip strength using a force dynamometer can be an additional metric for postoperative monitoring to identify patients with postoperative muscle weakness.

Limitations

Though the study was not designed to evaluate the possible interactions of both patient- and anesthesia-related factors, it is possible that gender, pharmacological interactions of propofol or inhalational agents, and NMBA can also influence recovery, and this can be of further research interest. It did not consider other possible risk factors, such as other drug interactions, and plasma concentrations of electrolytes,[26] although the potential confounding conditions were excluded. Both patient's and investigator's performance influence the testing of muscle power. This interindividual bias was minimized by performing all measurements as the best of three attempts. The best effort at every time point was analyzed and expressed as a percentage of preoperative baseline measurement in each patient. This study is not sufficiently powered to evaluate the additional clinical, physiological, and psychological consequences of reduced muscle power and PEFR. The sample size was based on the primary objective using *t*-test and not for correlation and Kaplan–Meyer analysis. The sample size may not be sufficient to establish the role of the dynamometer in routine clinical practice, but this could be a starting point for future investigation due to its potential role as a monitor for perioperative residual muscle weakness.

Conclusion

There was a significant reduction in the handgrip strength in the perioperative period, even when patients were extubated at a TOFR of >0.9 and the TOF returned to unity. The reduction in muscle power was 30% at 1 h, with the PEFR also reducing by about 28%, indicating a significant negative impact of motor power on the pulmonary function. Objective assessment of handgrip strength can identify muscle weakness, as clinical signs (head lift, handgrip) are insensitive indicators. The force dynamometer is an accessible, simple, and inexpensive equipment that improves the ability to identify and monitor PRMB objectively. Muscle grip strength has the potential to be a new metric for postoperative monitoring to identify patients with postoperative muscle weakness.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Level of consciousness	
Awake and oriented	2
Arousable with minimal stimulation	1
Responsive only to tactile stimulation	0
Physical activity	
Able to move all extremities on command	2
Some weakness in movement of extremities	1
Unable to voluntarily move extremities	0
Hemo-dynamic stability	
Mean arterial pressure $<15\%$ of baseline value	2
Mean arterial pressure 15–30% of baseline value	1
Mean arterial pressure $>30\%$ below baseline value	0
Respiratory stability	
Able to breathe deeply	2
Tachypnea with good cough	1
Dyspneic with weak cough	0
Oxygen saturation status	
Maintains value $>90\%$ on room air	2
Requires supplemental oxygen (nasal cannula)	1
Saturation $<90\%$ with supplemental oxygen	0
Postoperative pain assessment	
None or mild discomfort	2
Moderate to severe pain controlled with IV analgesics	1
Persistent severe pain	0
Postoperative emetic symptoms	
None to mild nausea with no active vomiting	2
Transient vomiting or retching	1
Persistent moderate to severe nausea and vomiting	0

Appendix 1: Fast Track score. IV = intravenous