ORIGINAL CLINICAL RESEARCH REPORT

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Reduction of Nonoperative Time Using the Induction Room, Parallel Processing, and Sugammadex: A Randomized Clinical Trial

Roland Kaddoum, MD, Said Tarraf, MD, Fadia M. Shebbo, MSc, Arwa Bou Ali, MPH, Cynthia Karam, MD, Carol Abi Shadid, MD, Joanna Bouez, MD, and Marie T. Aouad, MD

BACKGROUND: An important variable in the operating room is the nonoperative time (NOT), the time between skin closure on a previous case and skin incision on the following case. Mismanagement of NOT can result in significant financial losses and delays in the operating room (OR) schedule, which can negatively impact efficiency and patient, surgeon, and staff satisfaction. NOT includes general anesthesia induction time (IT), emergence time (ET), and turnover time (TOT), and can be calculated by adding the 3 components. OR efficiency can be increased by applying parallel processing for general anesthesia induction and OR cleaning and reversal of neuromuscular blockade with sugammadex to reduce the 3 components of NOT without compromising patient safety.
METHODS: This is a prospective, randomized study of 111 patients 18 to 75 years of age, American Society of Anesthesiologists (ASA) I–III, undergoing surgery requiring general anesthesia and muscle relaxation. Patients were randomly assigned to the control group (traditional linear processing for induction of anesthesia and OR cleaning and neuromuscular blockade reversal with neostigmine/glycopyrrolate) and the active group (parallel processing for induction of anesthesia and OR cleaning and neuromuscular blockade reversal with sugammadex). The primary outcome measured is the difference in the NOT. The secondary outcomes are surgeon and patient satisfaction.
RESULTS: NOT was significantly shorter in patients who underwent the parallel processing strategy and received sugammadex compared to the patients in the control group (25.0 [18.0–44.0] vs 48.0 [40.0–64.5] minutes; Cliff' delta = 0.57; $P < .001$). After excluding the cases in the experimental group that were put into sleep in the OR (ie, the first case of the room), IT, ET, TOT, and NOT were further reduced and remained statistically significantly lower than the control group. Satisfaction scores from surgeons were significantly higher in the active group than in the control group ($P < .001$). There was no significant difference in the satisfaction scores of patients between the 2 groups.
CONCLUSIONS: Our study showed that interventions, such as parallel processing during induction of anesthesia and room cleaning instead of linear processing and the use of the faster-acting sugammadex instead of the combination of neostigmine and glycopyrrolate for the reversal of rocuronium-induced neuromuscular blockade, resulted in shorter IT, ET, TOT, and therefore NOT, in addition to higher surgeon's satisfaction. (Anesth Analg 2022;135:406–13)

KEY POINTS

- **Question:** Is a reprocessing approach in the operating rooms along with the use of sugammadex instead of neostigmine/glycopyrrolate combination effective in reducing nonoperative time?
- **Finding:** Parallel processing during the induction of anesthesia and the use of sugammadex resulted in a significantly lower nonoperative time, better surgeon's satisfaction without affecting the patient's satisfaction, compared to the linear fashion with the use of neostigmine/glycopyrrolate.
- **Meaning:** A parallel processing paradigm in the operating room with the use of sugammadex increases operating room efficiency without altering the quality of care and satisfaction of patients.

GLOSSARY

ASA = American Society of Anesthesiologists; **AUBMC** = American University of Beirut Medical Center; **CONSORT** = Consolidated Standards of Reporting Trials; **ET** = emergence time; **IQR** = interquartile range; **IRB** = institutional review board; **IT** = induction time; **IV** = intravenous; **NOT** = nonoperative time; **OR** = operating room; **PACU** = postanesthesia care unit; **SD** = standard deviation; **TOF** = train-of-four; **TOT** = turn-over time

From the Department of Anesthesiology and Pain Medicine, American University of Beirut Medical Center, Beirut, Lebanon.

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R. Kaddoum and S. Tarraf contributed equally.

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Address correspondence to Marie T. Aouad, MD, Department of Anesthesiology and Pain Medicine, American University of Beirut Medical Center, PO Box 11-0236, Hamra, Beirut 1107 2020, Lebanon. Address e-mail to mm01@aub.edu.lb.

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Operating room (OR) efficiency is of paramount importance for hospitals, mainly because it is a high-cost unit. An important variable looked on in the OR is the nonoperative time (NOT) defined as the time between skin closure on the previous case and skin incision on the following case. Mismanagement of NOT can result in significant financial losses and delays in the schedule. This can negatively impact OR efficiency, along with patient's, surgeon's, and staff's satisfaction. In fact, many patients report that the waiting time before the surgery is a major cause of anxiety, and failure to address such a concern may largely affect patient satisfaction, one very important quality indicator in many hospitals. Although not the only one, NOT could be a significant contributor to case delays. In an ambulatory surgery setting, case delay was associated with a higher risk of complaints.[1] Furthermore, patients who experienced greater delays gave lower satisfaction rating than those who waited the least.[2] Therefore, nonclinical care components are considered by patients as an integral part of their care.[2] The surgeon also benefits from reduced NOT, as he or she can perform more surgical procedures in his or her own allocated OR time. Finally, an increased workflow efficiency translates into higher satisfaction rates for OR staff, due to the resultant decline in overtime hours.[3–5] Reducing NOT is a goal many institutions strive to achieve, and it requires the mobilization of financial and human resources to achieve maximal benefits. Also, reduction in turnover time (TOT) results in staffing costs' reduction by reducing allocated OR time.[6] Overall, the hospital will reap worthwhile benefits from improving OR efficiency because it is a high-cost department where the cost of 1 minute can reach up to $133 in US hospitals.[7] OR efficiency projects in multiple hospitals have shown significant cost reduction and savings that can reach millions of dollars per year.[8]

NOT or TOT is only 1 of the 8 factors that influence OR efficiency.[9] However, it receives lots of attention from OR managers because it is a key satisfier for surgeons.[9] NOT includes general anesthesia induction time (IT), emergence time (ET), and TOT, and can be calculated by adding the 3 components. IT of general anesthesia can be prolonged due to difficult vascular access, the need for additional lines or regional blocks, or the inability to rapidly secure the airway. ET that starts when the patient is handed over by the surgical team to the anesthesia team can be prolonged when delays in removing the endotracheal tube due to residual hypnotics or neuromuscular blockade happen. TOT is defined as the time from when the patient's bed exited the OR to the time when the next patient's bed entered the OR. It is mostly affected by the readiness of the housekeeping staff to clean the room and the nursing team to prepare the area for the next patient.

Our current practice at the American University of Beirut Medical Center (AUBMC) follows a linear processing technique: the patient is brought to the induction room for IV-line insertion and chart review and then transferred to the OR as soon as the room is cleaned after the end of the previous surgical procedure. Once inside the room, American Society of Anesthesiologists (ASA) standard monitors are applied, and anesthesia can be administered. At the end of the procedure, hypnotic agents are weaned, and reversal of neuromuscular blockade is achieved using a combination of an acetylcholinesterase inhibitor (eg, neostigmine) and an antimuscarinic agent (eg, glycopyrrolate).

We hypothesized that OR efficiency can be increased by applying multidisciplinary measures that involve the medical teams, as well as OR staff and housekeeping. These measures will reduce the 3 components of NOT without compromising patient safety:

1. IT can be reduced by switching from linear processing to parallel processing, ie, the following patient is brought to the induction room before the end of the previous surgery to be assessed and to receive general anesthesia. This way, the patient can be handed off to the surgery team as soon as the previous patient is wheeled out, and the OR is cleaned.
2. ET can be reduced by reversing neuromuscular blockade using the faster-acting sugammadex (Bridion 100 mg/mL, Patheon Manufacturing Services LLC) rather than the combination of neostigmine and glycopyrrolate. Sugammadex reverses neuromuscular blockade irrespective of its depth, in an average of 3 minutes.[10,11] The depth of the block dictates the dose of sugammadex to be used, with higher doses required for deeper levels of the block. Neostigmine/glycopyrrolate cannot reverse profound and deep blockade; it is recommended to be administered only after a degree of recovery from neuromuscular blockade is evident (ie, train-of-four [TOF] count is 2–4). Moreover, it cannot instantaneously and completely antagonize blockade, and it takes approximately 10 minutes to reach peak effect.[12]
3. TOT can be reduced by using parallel processing, by calling the housekeeping team ahead of time and have them ready to go into the OR for cleaning as soon as the surgical dressing is applied by the surgical team.

METHODS

This study was approved by the University's institutional review board (IRB ID ANES.RK.04), and

written informed consent was obtained from all subjects participating in the trial. The clinical trial was registered before patient enrollment at clinicaltrials.gov (NCT01937247, principal investigator: Roland Kaddoum, date of registration: September 9, 2013) and followed the CONSORT reporting guidelines for clinical trials.

After obtaining a written informed consent, 120 patients between 18 and 75 years of age undergoing surgery requiring general anesthesia and muscle relaxation were enrolled in the study from May 2018 through June 2020. All ASA physical status I–III patients were approached to be a part of the study. Exclusion criteria included patient or surgeon's refusal, emergency surgery, invasive line placement (arterial line and central line), difficult airway requiring awake fiberoptic intubation, known allergy to sugammadex, neostigmine, or glycopyrrolate, and infected cases that require decontamination of the room.

The team involved in patient care, including the attending anesthesiologist, the anesthesia resident, the anesthesia nurse, the nursing team, and the surgeon, were informed about the study and its steps. Patients and surgeons were blinded to the patient's allocation. However, due to the nature of the study, blinding of the anesthesia staff performing the procedure was not possible because the parallel processing cannot be concealed. All data were measured and recorded by 1 of the research team members who could not be blinded to the study group allocation but who also was not involved in the anesthetic management of the case. However, the variables collected had very clear definitions and were cross-validated through the institutional electronic health record by a blinded outcome assessor.

Cluster randomization was done by day, using a computerized randomizer, regardless of the number of ORs allocated to the study and the number of patients recruited on that day. For instance, eligible ORs defined the eligible patients. These ORs were identified ahead of time and assigned to a randomization arm. Proper concealment was ensured using the central randomization process where the person recruiting calls the research coordinator to allocate each enrolled room with its patients to 1 of the 2 groups. The number of patients recruited was revisited regularly until the minimum required number of patients is achieved in both groups. Our randomization ended up with a 1:1 ratio. In group A (active group/parallel processing), the first patient of the day in a specific room received induction of general anesthesia in the OR using propofol, fentanyl, lidocaine, and rocuronium to facilitate tracheal intubation. Throughout the surgery, anesthesia was maintained using sevoflurane and boluses of fentanyl as needed, and the patient was kept paralyzed using rocuronium. At the end of surgery, sevoflurane was weaned and then discontinued. After placement of the surgical dressing, the registered nurse called in the housekeeping team to start cleaning of the OR. After the drapes were taken down, the patient was reversed with sugammadex 2 to 4 mg/kg, depending on the depth of the neuromuscular blockade assessed using the TOF ratio at the adductor pollicis, and then extubated before being moved out of the OR to the post-anesthesia care unit (PACU). Meanwhile, 15 minutes before the end of the surgery, the next patient was rolled into the induction room where induction of anesthesia was started 5 minutes before the estimated end of the previous case. Once the nursing team gave clearance for the next patient to enter the OR, the anesthesia resident or nurse rolled the next patient (who already received induction of general anesthesia in the induction room) into the OR.

In group B (control group/linear processing), the first patient of the day in a specific room received induction of general anesthesia in the OR using propofol, fentanyl, lidocaine, and rocuronium to facilitate tracheal intubation. During surgery, the patient was maintained using sevoflurane, and boluses of fentanyl as needed. Muscle relaxation was achieved using rocuronium. Meanwhile, 15 minutes before the end of surgery, the next patient was rolled into the induction room where an IV was started. At the end of surgery, sevoflurane was weaned and then discontinued. Once signs of spontaneous recovery were documented with TOF showing 4 twitches at the adductor pollicis, neuromuscular blockade was reversed with neostigmine 50 μg/kg and glycopyrrolate 10 μg/kg, and the patient was extubated. Then, the patient was moved out of the OR to the PACU. At this point, the housekeeping team started cleaning the OR and the next patient was wheeled into the OR for induction of general anesthesia.

Figure 1 illustrates the patient's surgical flow in both the control and the active groups.

IT is defined as the time interval between arrival to the OR and patient handover to surgical team. ET is defined as the time interval between end of surgery and patient wheeled out of the OR. TOT is defined as the time from when the patient's bed exited the OR to the time when the next patient's bed entered the OR. Patients' characteristics were recorded, as well as IT, ET, and TOT for each patient in a specific room. NOT was calculated as the sum of IT, ET, and TOT.

The surgeon was asked to rate his satisfaction at the end of the day using a 5-point Likert scale. Patients were closely followed up throughout the study and till discharge from PACU to check for the occurrence of any side effects and provide proper treatment as per the institution's routine practice. On

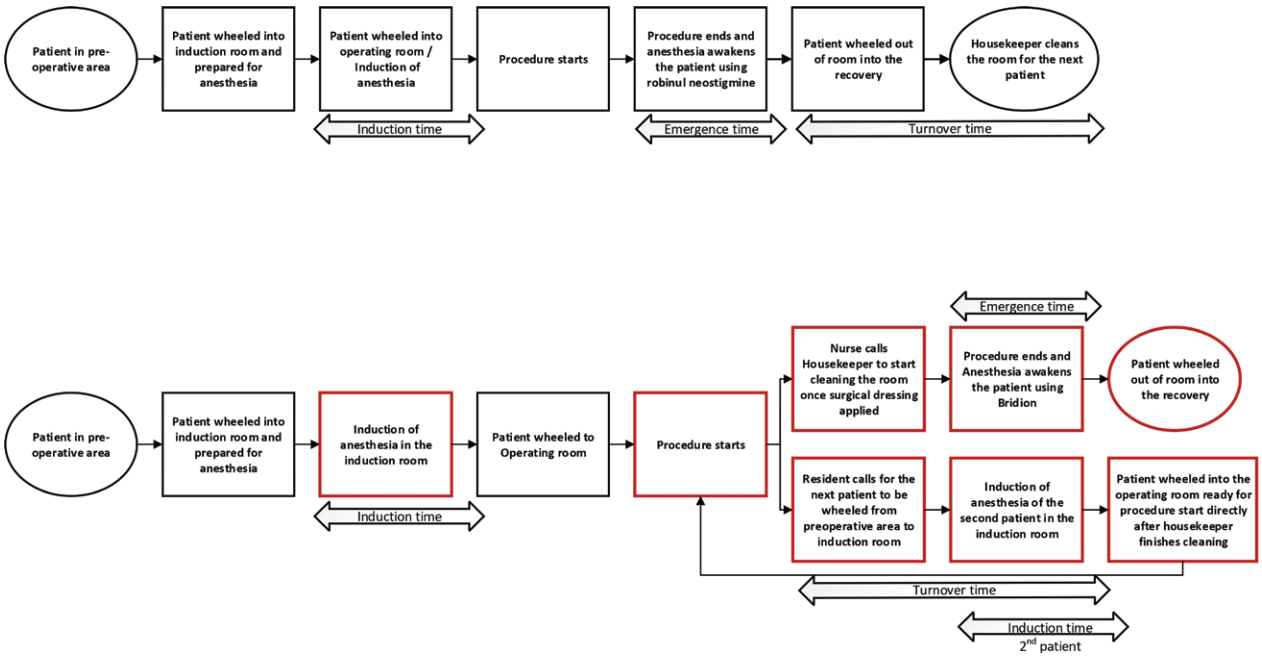

Figure 1. Patient's surgical flow in the 2 study groups.

postoperative day 1, the clinical research assistant called each patient and asked them how they would rate their overall anesthesia experience on a 5-point Likert scale, starting from the moment they entered the induction room until their exit from the PACU.

The primary outcome is improvement in the NOT. The secondary outcomes are surgeon and patient satisfaction.

Statistical Analysis

Normally distributed data were tested using Student *t* test for continuous variables and Pearson's χ^2 test for categorical variables. We used the Shapiro-Wilk test to check for significant differences between our data distribution and the normal distribution. Normally distributed data (baseline variables) were presented as mean ± SD and analyzed using the independent Student *t* test. Nonparametric data (primary outcome variables) were presented as median (IQR) and were analyzed using the Mann-Whitney U test. Categorical variables (sex, ASA score, surgery type, surgical wound classification, patient satisfaction score, and surgeon satisfaction score) were reported as numbers and percentages. Level of significance was considered at 0.05 level.

Sample Size Calculation

A pilot study conducted at AUBMC showed that the mean NOT per patient in the standard practice was 45 ± 15 minutes. We considered a mean difference of 7 minutes per patient to be a clinically meaningful difference. With a standard deviation of 15, a power of 80%, and $\alpha = 0.05$, sample size calculation yielded a minimum of 56 patients in each group.

RESULTS

A total of 120 patients were enrolled in the study, out of which 9 patients were excluded (8 patients underwent spinal anesthesia and 1 patient did not meet the inclusion criteria). Therefore, we included a total of 111 patients in our analysis (Figure 2). The study was conducted during 56 OR days with 32 ORs having an average of 3 cases and 24 ORs having 1 case each. Baseline characteristics of our study population were comparable between the 2 groups and are summarized in Table 1.

Primary Outcome

NOT, which is the summation of the IT, ET, and TOT, was significantly shorter in patients who underwent the parallel processing strategy and received sugammadex compared to the patients in the control group (25.0 [18.0–44.0] vs 48.0 [40.0–64.5] minutes; Cliff' delta = 0.57; $P < .001$). Perioperative times per patient are presented in Table 2.

Additional Analysis

We further analyzed our primary outcome after excluding the cases in the active group that received induction of general anesthesia in the OR (ie, the first case of the room) to reflect on scenarios where the schedule is congested, and many cases are scheduled in 1 OR to follow each other. The median times of IT, ET, TOT, and NOT were further reduced to 2.0

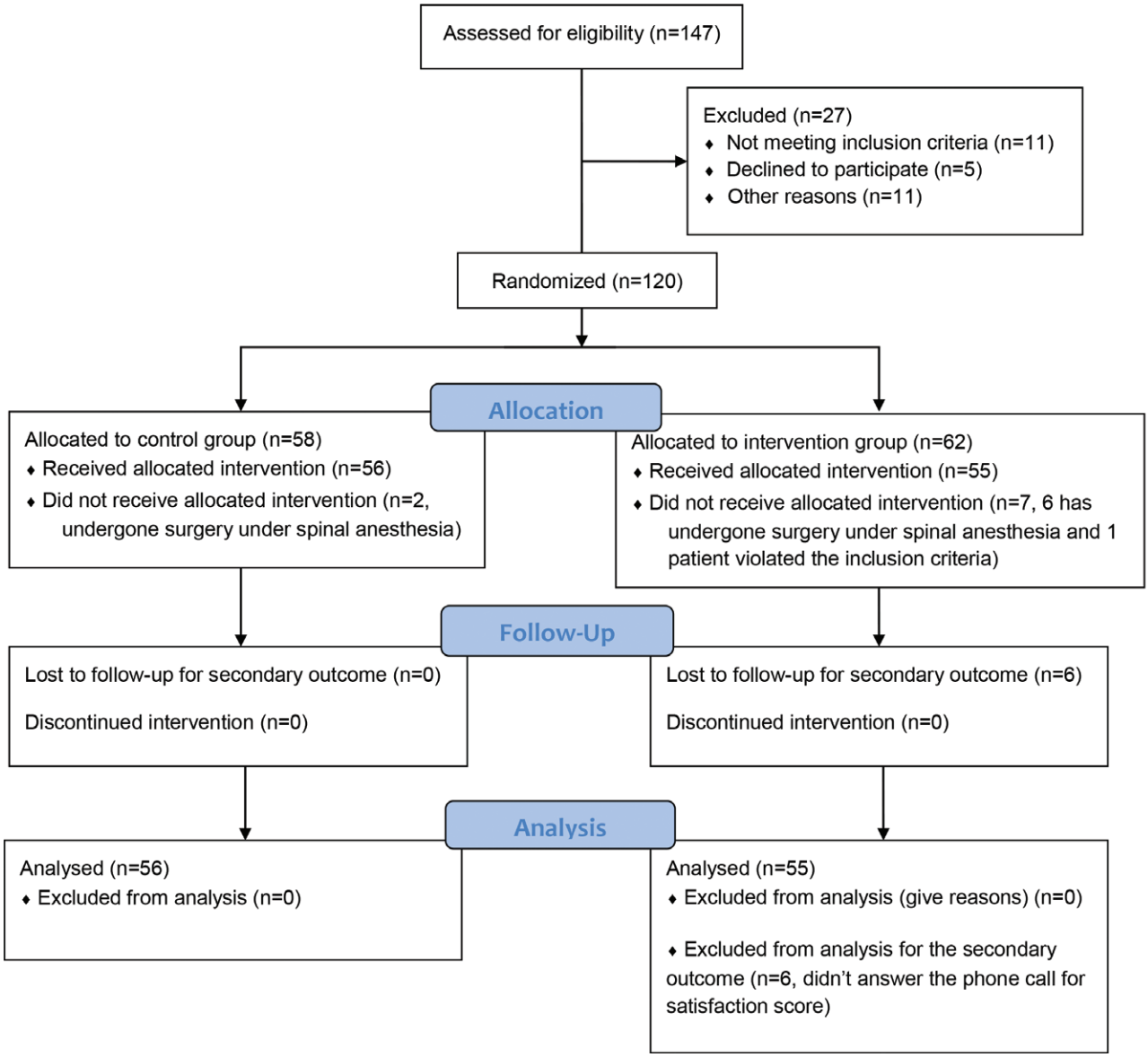

Figure 2. CONSORT flow diagram of the patients' enrollment. CONSORT indicates Consolidated Standards of Reporting Trials.

(2.0–4.0), 7.0 (5.0–10.0), 7.0 (5.0–13), and 20.0 (15.0–23.0) minutes with $P \leq .001$, respectively, as compared to the control group.

Secondary Outcome

Satisfaction scores from surgeons were significantly higher in the active group than in the control group. However, there was no significant difference in the satisfaction scores of patients between the 2 groups. Satisfaction scores are depicted in Table 3.

DISCUSSION

Our study showed that applying a multidisciplinary protocol that includes coordinated interventions by anesthesia, nursing, and housekeeping teams reduces NOT and improves surgeons' satisfaction while maintaining a safe perioperative environment. Previous studies showed that improving OR efficiency by reducing NOT increases patient, surgeon, and staff satisfaction.[2,8] In addition, it brings economic benefits to the institution by allowing more surgeries to be scheduled in a given timeframe, and limiting overtime pay to the OR staff.[3–5]

What is unique about our study is that it used a multimodal approach that targeted all 3 components of NOT. In our study, we implemented interventions specifically tailored to decrease IT, ET, and TOT. The use of sugammadex to shorten ET combined with parallel processing to reduce IT by inducing the patient with general anesthesia in the induction room and TOT by calling in the housekeeping team to enter the OR as soon as the surgical dressing is applied resulted

Table 1. Baseline Characteristics

Characteristics	Control, n = 56	Active, n = 55	Effect size[a]
Age, y	42.70 ± 13.73	43.95 ± 15.7	0.08
Sex, F/M	26 (46.4)/30 (53.6)	18 (32.7)/37 (67.3)	0.14
Weight, kg	87.71 ± 19.36	85.80 ± 20.37	0.09
ASA			
I	5 (8.9)	9 (16.4)	0.18
II	51 (91.1)	44 (80)	
III	0 (0)	2 (3.6)	
Surgery type			
Hernia	7 (12.5)	12 (21.8)	0.48
Laparoscopic cholecystectomy	13 (23.2)	14 (25.5)	
Sleeve gastrectomy	13 (23.2)	8 (14.5)	
Others	23 (41.1)	21 (38.2)	
Surgical wound classification			
Clean	42 (75)	35 (63.6)	0.14
Clean-contaminated	12 (21.4)	16 (29.1)	
Contaminated	1 (1.8)	3 (5.5)	
Dirty	1 (1.8)	1 (1.8)	

Data are presented as mean ± SD or n (%).
Abbreviations: ASA, American Society of Anesthesiologists; SD, standard deviation.
[a]Cohen's d is reported for means, and Phi and Cramer's V is reported for proportions.

Table 2. Nonoperative Time per Patient

Nonoperative time	Control, n = 56	Active, n = 55	Effect size[a]	*P* value
Induction time, min	14.5 (10.3–21.8)	7.0 (2.0–14.0)	0.57	<.001
Emergence time, min	12.0 (7.0–17.8)	8.0 (6.0–12.0)	0.32	.003
Turnover time, min	17.0 (13–24.5)	10.0 (6.0–16.0)	0.41	<.001
Nonoperative time, min	48.0 (40.0–64.5)	25.0 (18.0–44.0)	0.57	<.001

Data are presented as median (IQR).
[a]Cliffs' delta is reported.
Abbreviation: IQR, interquartile range.

in an additive decrease in overall TOT. Our data show that IT, ET, TOT, and NOT were all significantly lower in the active group, as compared to the control group when interventions such as parallel processing for induction of anesthesia and OR cleaning, and sugammadex use were implemented as opposed to the traditional linear processing and neuromuscular blockade reversal with neostigmine.

Parallel processing implies that 2 anesthesia teams are taking care of 2 patients simultaneously; while 1 patient is being induced in the induction room and the other is being extubated in the OR, reducing, therefore, the lag time that would de facto exist in the case of linear processing. The literature is scarce on articles highlighting the contribution of parallel processing to the reduction in TOT. Sokolovic et al[13] looked at the reduction in TOT when an overlapping strategy, ie, parallel processing, was followed, and concluded that TOT decreased significantly from 65 to 52 minutes. This reduction came at the expense of an increase in anesthesia staffing. Kodali et al[14] looked at the contribution of various operational changes to workflows to the reduction of TOT and found a statistically significant reduction in both the general and gastrointestinal surgery ORs (44.8 versus 48.6 minutes) and other subspecialties (49.3 versus 53.0 minutes) in the study group as compared to the control group, respectively. These findings are similar to ours where a significant reduction in TOT was found in the parallel processing group versus the linear processing/control group (10 versus 17 minutes), despite the fact that the percent decrease of TOT was larger in our study. The presence of induction rooms at our institution allowed us to start general anesthesia in the induction room versus the main OR, thus eliminating IT.

The use of sugammadex has also facilitated the implementation of protocols to increase OR efficiency. The fast reversal of rocuronium-induced neuromuscular blockade by sugammadex as compared to the combination of neostigmine and glycopyrrolate with an average of 3 versus 10 minutes, respectively, resulted in a faster ET, and subsequently, a faster OR discharge time.[15,16] Our study showed that median ET was 8.0 minutes in the study group as compared to 12.0 minutes in the control group. This significantly shorter time is largely attributable to the use of sugammadex that allowed a faster reversal of neuromuscular blockade, and subsequent endotracheal extubation. Our results are compared to those by Putz et al[17] showing a faster OR discharge, ie, ET, in the sugammadex group as compared to the neostigmine/glycopyrrolate group (9.15 ± 4.28 versus 13.87 ± 11.43 minutes). Another study by Brueckmann et al[18] showed a similar pattern of a decreased ET when

Table 3. Satisfaction Scores

Satisfaction	Control, n = 56	Active, n = 55	Effect size	*P* value
NRS, patient satisfaction[a]				
Strongly dissatisfied	1 (1.8)	0 (0)	0.187	.453
Dissatisfied	2 (3.6)	0 (0)		
Neutral	2 (3.6)	4 (8.2)		
Satisfied	32 (57.1)	27 (55.1)		
Strongly satisfied	19 (33.9)	18 (36.7)		
NRS, surgeon satisfaction				
Neutral	8 (14.3)	1 (1.8)	0.54	<.001
Satisfied	38 (67.9)	15 (27.3)		
Strongly satisfied	10 (17.9)	39 (70.9)		

Data are presented as n (%).
Abbreviation: NRS, numerical rating scale.
[a]49 patients analyzed from the active group.

sugammadex was used instead of the traditional reversal (14.7 versus 18.6 minutes), albeit the ET in this study was higher in both groups as compared to our study, which could be attributed to different OR discharge criteria and protocols.

Parallel processing also applies to the cleaning process. Starting the cleaning of the room while the patient is still in the OR adds to the time spared by a parallel induction of general anesthesia and a swift emergence. Several studies were able to prove that a parallel processing approach is efficient in decreasing the NOT that reflects on a better OR efficiency and higher throughput.[6,19–21] Sandberg et al[20] experienced a redesigned OR to perform parallel processing and compared its efficiency to standard ORs. They successfully showed a significant reduction in NOT from 67 to 38 minutes.[20] Similarly, our interventions resulted in a cumulative decrease in NOT per patient from approximately 48 minutes in the control group to 25 minutes in the active group.

Surgeon satisfaction and patient satisfaction were also secondary outcomes that were assessed in the study we conducted. We recorded higher satisfaction scores for surgeons when participating in the intervention category as compared to when they were operating on patients in the control group, 70.9% versus 17.9% as strongly satisfied, respectively. This finding confirms our initial hypothesis that faster TOT increases surgeon satisfaction by decreasing lag times and allowing an earlier wrap-up of the operating schedule. Patients reported higher satisfaction scores in the intervention group as compared to the control group, but this difference was not statistically significant. In fact, the overall individual patient experience is not significantly altered by the parallel processing and sugammadex interventions as the difference in the waiting times is not that clinically significant for the individual patient, except maybe for the last patients being operated on by the same surgeon, as the cumulative time saved would significantly affect their waiting times.

This study has several limitations that might hinder its wide applicability. In practice, if such a model was to be applied on a large scale, it would require a mandatory increase in anesthesia personnel to be able to safely handle overlapping inductions and emergences. In addition to that, additional anesthesia machines and monitoring devices need to be installed in the induction rooms to allow for safe intubations and proper monitoring until the patient is escorted into the operating theater. This will require hospitals to invest more money before they can achieve cost savings on the long term. Furthermore, modern operating theaters may be lacking induction rooms, which makes the reduction of IT time impossible. Moreover, the use of a high-cost medication such as sugammadex incurs increased costs of the patient's bill. This can limit its widespread use for the sole purpose of increasing OR efficiency. Furthermore, blinding of the data collector was not possible due to study design. However, we believe that bias was not introduced because the time intervals related to the study end points were clearly defined.

In conclusion, our study showed that interventions such as parallel processing during induction of anesthesia and room cleaning instead of linear processing and the use of the faster-acting sugammadex instead of the combination of neostigmine and glycopyrrolate for the reversal of rocuronium-induced neuromuscular blockade resulted in shorter IT, ET, TOT, and NOT, in addition to higher surgeon's satisfaction. This theoretically translates into an increase in economic benefits for the institution by allowing more surgeries to be scheduled during a given time slot. It also results in saving overtime money paid to the OR staff. However, this multimodal strategy can only be used if additional resources and manpower can be mobilized. Induction rooms equipped with anesthesia machines and monitors, as well as additional anesthesia personnel are prerequisites for the safe implementation of such protocols. Future large-scale projects can benefit from experimenting the approach implemented in our report to study its effects on satisfaction profiles of the whole medical team involved and its cost effectiveness by using well-defined and structured tools and compared it to traditional processes. ■

DISCLOSURES

Name: Roland Kaddoum, MD.
Contribution: This author helped with the study conception and design, proposal writing, and data interpretation, as well as drafting, revising, and approving the final version of the manuscript.
Name: Said Tarraf, MD.
Contribution: This author helped with the study conception and design, proposal writing, and data interpretation, as well

as drafting, revising, and approving the final version of the manuscript.
Name: Fadia M. Shebbo, MSc.
Contribution: This author helped with data collection, data management, and analysis, as well as drafting, revising, and approving the final version of the manuscript.
Name: Arwa Bou Ali, MPH.
Contribution: This author helped with study design, data collection, and revising and approving the final version of the manuscript.
Name: Cynthia Karam, MD.
Contribution: This author helped with study design, data interpretation, and revising and approving the final version of the manuscript.
Name: Carol Abi Shadid, MD.
Contribution: This author helped with data collection and interpretation, as well as drafting and approving the final version of the manuscript.
Name: Joanna Bouez, MD.
Contribution: This author helped with data collection and interpretation, and revising and approving the final version of the manuscript.
Name: Marie T. Aouad, MD.
Contribution: This author helped with study conception and design, proposal writing, and data interpretation, as well as drafting, revising, and approving the final version of the manuscript.
This manuscript was handled by: Zeev N. Kain, MD, MBA.

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