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NEUROMUSCULAR BLOCKADE (GS MURPHY, SECTION EDITOR)

# Deep Neuromuscular Blockade: Does the Data Support Its Use in Surgical Patients?

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## Abstract

**Purpose of Review** This review aims to provide an update about the role of deep neuromuscular blockade (NMB) in surgery by providing an overview the literature of the last 3 years.

**Recent Findings** Since the approval of sugammadex for the reversal of deep NMB, the influence of deep NMB on facilitation of surgery as well as postoperative patient outcome has become the focus of increased interest in research. Though deep NMB is still predominantly investigated in the setting of laparoscopic surgery, some recent publications have also investigated deep block in other patient populations.

**Summary** Deep NMB has become increasingly popular and intensely researched. Mounting evidence has documented that surgical conditions are improved when deep (vs. moderate) neuromuscular blockade is used. Though this is true for many, it may not be applicable to all surgical procedures. Previously not well documented, deep vs. moderate NMB may also influence postoperative patient outcome by a reduction in surgical complication rates and/or decreased postoperative pain after certain procedures.

**Keywords** Deep neuromuscular blockade · Surgical conditions · Laparoscopy · Moderate neuromuscular blockade · Patient outcome · Pneumoperitoneum

## Introduction

The introduction of neuromuscular blocking agents (NMBA) into anaesthesia practice by Griffith and Johnson in 1942 has undoubtedly revolutionized surgery by facilitating procedures which were previously considered impossible [1]. Not surprisingly, Barash et al. quoted the corresponding article by Griffith and Johnson as no. 13 of the top 20 most important anaesthesia articles ever published [2]. Of interest, another 'top-20 contender' named in the same paper is a study by Beecher and Todd describing the dangers of recurarization, or residual neuromuscular block (RNMB), resulting in a five times increased anaesthesia-related mortality [3]. Though pharmacological reversal of RNMB with cholinesterase-inhibitors has been the gold standard for over 50 years, the incidence of RNMB and the problems associated with the condition have retained an unacceptably high incidence [4]. Multifactorial in nature, RNMB is a dilemma many anesthesiologists are facing in daily routine: surgeons are not infrequently demanding deep NMB even towards the end of a procedure, but time pressures also dictate swift patient turnovers. In the context of the fact that cholinesterase-inhibitors are neither fast-acting nor suitable for the reversal of deep NMB, until recently, RNMB has thus been an almost inevitable outcome. However, the introduction of sugammadex in Europe in 2008 and more recently in the USA (12/2015) has changed the game once more: maintenance of deep block throughout surgery as well as its swift reversal has become feasible. Though this revolution in pharmacological reversal of (amino-steroidal) neuromuscular blocking agents (NMBA) may potentially be suited to significantly reduce the incidence of RNMB, the high costs for the drug as well as the fear of side effects such as anaphylaxis (to both, NMBA as well as sugammadex) have yet hindered its introduction into routine practice in many countries, including the USA. In the setting

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of ever-increasing healthcare costs, and with the intention not to expose patients to an unnecessary risk, the indication for deep NMB has therefore been controversially debated [5].

Aim of the current narrative review is to provide a brief overview about the deep NMB-associated literature since the last comprehensive metanalysis of the topic published in 2017.

## Methods

This narrative review is based on a PubMed database search including the time frame from December 2016 to December 2019, using the search terms 'deep neuromuscular block', 'deep block', 'moderate block', 'operating conditions', surgical conditions' and "outcome'.

As prior to the meta-analysis by Bruintjes et.al. [6], most studies comparing different levels of NMB suffered from either using comparisons of little clinical relevance (i.e. no vs. deep NMB) or the lack of a clear definition of block depth; the generally accepted nomenclature of NMB is provided below:

*Profound or Intense NMB:* No response in either train-of-four (TOF) or post-tetanic count (PTC).
*Deep NMB:* No response in the TOF and 1–5 twitches in the PTC.
*Moderate NMB:* A TOF of 1–3 twitches.
*Shallow NMB:* 4 twitches in the TOF with fade.
*No NMB/full reversal:* A TOF ratio of at least 90%.

The review is partitioned into two main sections: deep NMB in (1) laparoscopic and (2) non-laparoscopic surgeries. Each section of the review is headed by a summary and then followed by a more in-depth description of individual studies. Tables 1 and 2 summarize pro vs. con findings of individual trials regarding the effects of deep vs. moderate NMB.

## Review

### 2017 Metanalysis

The aforementioned metanalysis by Bruintjes et.al. [6] published in 2017 has been set as the starting point for the following review. The authors investigated deep vs. moderate NMB and their effect in the setting of laparoscopic surgery, until today the by far most frequently researched surgical setting. The primary outcome parameter was the quality of surgical space conditions. Secondary outcomes were postoperative pain, conversion to higher pressure pneumoperitoneum or open surgery, duration of surgery, intraoperative complications and length of hospital stay.

Bruintjes et al. concluded that deep vs. moderate NMB appeared to improve surgical operating conditions, with a mean difference of 0.65 (95% CI 0.47–0.83) points on a 1–5-point (1 = poor to 5 = excellent) surgical rating scale. Despite this modest increase in surgical conditions, the use of deep NMB did not influence the duration of surgery. Deep NMB was found to facilitate the use of low-pressure pneumoperitoneum, predominantly by means of an increased compliance of the abdominal wall. Consequently, fewer conversions to higher pressure pneumoperitoneum were required under deep vs. moderate NMB. Though the data reviewed by Bruintjes et al. primarily focused on intraoperative conditions and not postoperative patient outcome, the authors did find a trend towards a reduction of early postoperative pain in the postoperative acute care unit (PACU) after deep vs. moderate NMB, with some studies observing lower pain scores up to 24 h after surgery. The metanalysis did not find proof for an influence of deep NMB on the hospital length of stay.

### Deep NMB in Laparoscopic Surgery Since 2017

**Summary** Seven trials were reviewed. Four trials found that deep vs. moderate NMB resulted in improved surgical conditions (more predictable, less sudden movement, less need to increase the intra-abdominal insufflation pressure). One study reported lower postoperative pain scores and one a significant association between poor operating conditions and post-surgical complications. Three studies (total $n = 212$ patients) did not find benefits for deep NMB when investigating the stress response ($n = 1$ trial), quality of recovery ($n = 1$trial) and operating conditions ($n = 1$ trial).

### Individual Studies

Baete et.al. [7••] conducted a randomized clinical trial in 60 patients undergoing laparoscopic bariatric surgery. Primary outcome parameters were the quality of surgical conditions assessed by a single surgeon using a 5-point rating scale (1 = extremely poor, 5 = optimal), the number of intra-abdominal pressure increases > 18 cmH2O and the duration of surgery. Secondary outcome measure was the postoperative pulmonary function assessed by peak expiratory flow, forced expiratory volume in 1 s and forced vital capacity, as well as the need for postoperative respiratory support.

There was no statistically significant difference in the surgeon's rating regarding the quality of the surgical field between the deep and moderate NMB group (4.2 ± 1.0 vs. 3.9 ± 1.1; $P = .16$, respectively; estimated treatment effect 0.4 [−0.1–0.9]). There was no difference in the proportional rating of surgical conditions over the 5-point rating scale between both groups ($P = 0.91$). The number of intra-abdominal pressure increases > 18 cmH2O and the duration of surgery were not statistically different between the deep and moderate

**Table 1** Studies indicating benefits of deep neuromuscular blockade

| Author | Study summary | Outcome |
|---|---|---|
| Casanova et al. 2017 [18] | Prospective, longitudinal observational trial; $n = 76$<br>Lung resection surgery; one-lung ventilation in lateral decubitus position<br>Comparing ventilator and hemodynamic data during intense deep and moderate NMB | • Peak, plateau and mean airway pressures significantly lower and compliance as well as peripheral oxygen saturation higher during intense and deep blockade (vs. moderate) |
| Madsen M. V. et al. 2017 [11] | Randomized double-blinded clinical trial; $n = 110$<br>Laparoscopic hysterectomy; deep vs. standard/moderate NMB with rocuronium | • No sudden abdominal contractions detected in the deep NMB group vs. 12 episodes in the standard NMB group ($P = 0.001$) |
| Madsen M. V. et al. 2017 [17•] | Randomized double-blinded trial; $n = 128$<br>Upper gastrointestinal laparotomy; deep vs. standard NMB | • Better subjective rating of surgical conditions with deep NMB<br>• 31 (49%) patients receiving standard NMB needed an anaesthetic intervention (bolus of neuromuscular blocking drug or increased depth of anaesthesia) compared with 11 (17%) patients receiving deep NMB<br>• No differences in operating time, occurrence of wound infection and wound dehiscence |
| Rosemberg J. et al. 2017 [12] | Randomized controlled blinded trial; $n = 127$<br>2 × 2 factorial design, laparoscopic cholecystectomy<br>Surgical conditions in deep vs. moderate NMB and low vs. standard insufflation pressure pneumoperitoneum<br>Pain score within 24 h postoperative (low-pressure pneumoperitoneum) | • No patient in the standard pressure groups vs. 12 patients in the low-pressure groups (7 moderate NMB and 5 deep NMB) required rescue intervention (increase in insufflation pressure and/or level of NMB)<br>• Deep NMB does not replace appropriate insufflation pressures<br>• No significant differences in shoulder pain between the groups |
| Ozdemir-van Brunschot D. M. d. et al. [15] | Multicentre randomized controlled blinded trial; $n = 34$<br>Laparoscopic donor nephrectomy<br>Group 1: low-pressure pneumoperitoneum (6 mmHg) and deep NMB (PTC 1–5) Group 2: low-pressure pneumoperitoneum and moderate NMB (TOF 0–1) | • Deep NMB facilities surgery by improving quality of surgical field<br>• Higher incidence of compilations with moderate NMB and low-pressure pneumoperitoneum |
| Soderstrom C. M. 2018 [13] | Randomized, blinded trial (single centred); $n = 34$<br>Laparoscopic ventral hernia repair<br>Deep vs. no NMB<br>Evaluation of surgical view on a 5-point rating scale<br>Surgical conditions during laparoscopic suturing of hernia defect | • No difference in rating for surgical view, but improved rating score while suturing the hernia defect with deep NMB |
| Fuchs-Buder T. et al. 2019 [8•] | Single-centre randomized controlled trial; $n = 85$<br>Laparoscopic bypass surgery in obese patients<br>Deep vs. moderate<br>Outcomes: surgical conditions, intra-abdominal pressure, time required to perform the gastro-jejunal anastomosis and peri-operative surgical complications. | • Improvement of surgical conditions in 29/34 patients with deep block vs. 4/31 with moderate block; $P = 0.0001$<br>• Poor surgical conditions more frequently associated with surgical complications (61.5 vs. 15.3%; $P = 0.0001$) |
| Oh S. K. et al. 2019 [20] | Prospective randomized controlled trial; $n = 83$<br>Lumbar spinal surgery<br>Deep NMB vs. no NMB | • Peak inspiratory and plateau airway pressure, as well as lumbar wound retractor pressure significantly lower with deep NMB<br>• Operating conditions better with deep NMB. Lower postroperative pain, rescue fentanyl consumption, less adverse hemodynamic events in PACU and shorter length of PACU stay after deep NMB |
| Laosuwan P. et al. 2019 [19] | Multicentre randomized parallel intervention trial; $n = 102$<br>Microscopic endolaryngeal surgery<br>Outcome: surgical rating conditions<br>DEEp NMB (PTC 1–2) vs. moderate NMB (TOF 1–2) | • Clinically acceptable surgical rating conditions in 49 patients (100%) with deep vs. 43 patients (89.6%) with moderate NMB ($P = 0.027$)<br>• More frequent vocal fold movement with moderate (70.8%) vs. deep NMB (32.7%)<br>• Additional doses of rocuronium required more often with moderate (47.9%) vs. deep NMB (20.4%); $P = 0.05$<br>• Better surgical rating conditions and anaesthetic conditions with deep NMB |

*NMB* neuromuscular block

NMB group (0.2 ± 0.9 vs. 0.3 ± 1.0; $P = 0.69$; estimated treatment effect − 0.1 [− 0.5–0.4] and 61.3 ± 15.1 min vs. 70.6 ± 20.8 min; $P = 0.07$, estimated treatment effect − 9.3 [− 18.8–0.1], respectively). All the pulmonary function tests were considerably impaired in both groups when compared with baseline ($P < 0.001$). However, no differences were found between deep vs. moderate NMB for any of the parameters of lung function.

**Table 2** Studies indicating no benefit of deep neuromuscular blockade

| Author | Study summary | Outcome |
|---|---|---|
| Baete S et.al. 2017 [9] | Randomized double-blind clinical trial $n = 60$<br>Laparoscopic bariatric surgery; deep vs. moderate NMB<br>Effect of NMB on surgical conditions and postoperative respiratory function | • No evidence for improved surgical conditions with deep NMB<br>• Decreased postoperative pulmonary function after both deep and moderate NMB compared with baseline (assessed by peak expiratory flow, forced vital capacity and forced expiratory volume in 1 s) |
| Ozdemir-van Brunschot D. M. D. et.al. 2017 [16] | Single-centre randomized controlled trial $n = 64$<br>Laparoscopic donor nephrectomy.<br>Deep NMB in both low-pressure (6 mmHg) and standard-pressure pneumoperitoneum (12 mmHg).<br>Primary outcome: overall score on the quality of recovery-40 QOR-40) questionnaire on postoperative day 1. | • No significant difference in QOR-40 score on day 1 between low and standard pressure group ($P = 0.06$)<br>• No difference in pain scores and analgesic consumption |
| Koo B.W. et.al. 2019 [18] | Randomized controlled trial $n = 88$ for laparoscopic gastrectomy with deep vs. moderate NMB<br>Outcome: stress response (interleukins, tumour necrosis factor) | • No difference in stress response |

*NMB* neuromuscular block

Thus, compared with a moderate NMB, there was insufficient evidence to conclude that deep NMB resulted in improved surgical conditions during laparoscopic bariatric surgery. Postoperative pulmonary function was substantially decreased after laparoscopic bariatric surgery independently of the NMB regime that was used.

Fuchs-Buder et.al. [8•] reported a single-centre, randomized controlled study at a University Hospital in France. Each patient scheduled for laparoscopic bariatric surgery was used as own control and examined twice: at the first evaluation (E1), all patients received a rocuronium-induced moderate NMB. Thereafter, all patients with less than excellent conditions were randomized to deep or moderate block and, after implementation (bolus dose of rocuronium vs. normal saline), a second evaluation (E2) was performed within 10 min. Patients with excellent rating at E1 were excluded from E2, as their surgical condition could not be further improved. The primary outcome parameter was an improvement in surgical conditions by switching from moderate to deep NMB. Secondary outcome measures were changes in intra-abdominal pressure, the time required to perform the gastro-jejunal anastomosis and peri-operative surgical complications.

Surgical conditions were assessed with a 4-point rating scale. Intraoperative adverse events were assessed with the Kaafarani-classification [9] and postoperative complications with the Clavien-Dindo classification [10]. Eighty-nine patients were initially included and data from 85 could be assessed at E1; surgical rating was excellent in 20, good in 35, acceptable in 18 and poor in 12. After excluding those with an excellent rating, the remaining 65 patients were randomly assigned to deep or moderate block. At E2, an improvement of surgical conditions was observed in 29 out of 34 patients with deep block and in only four out of 31 with moderate block; $P < 0.0001$. Poor surgical conditions were more frequently associated with surgical complications (61.5 vs. 15.3%; $P < 0.001$), without the depth of block being directly statistically related to this outcome measure.

Madsen M.V. et.al. [11] conducted a pre-planned secondary analysis of a randomized, controlled study in 110 patients scheduled for laparoscopic hysterectomy. All subjects were randomized into either deep NMB and 8 mmHg pneumoperitoneum (deep NMB group) or single-bolus NMB and 12 mmHg pneumoperitoneum (standard NMB group). NMB was established with rocuronium and reversed with sugammadex.

No sudden abdominal contractions were detected in the deep NMB group as compared with 12 episodes in the standard NMB group ($P < 0.001$). The insufflator alarmed in no vs. ten procedures ($P = 0.001$) in the deep and standard NMB group, respectively. The surgeon registered increasing abdominal tensions in no vs. eight procedures ($P = 0.006$) in the deep vs. the standard NMB group, respectively.

Deep NMB in combination with 8 mmHg pneumoperitoneum prevented sudden abdominal contractions during laparoscopic hysterectomy.

Rosenberg et.al. [12] compared the use of deep vs. moderate NMB, and lower (8 mmHg) vs. higher (12 mmHg, 'standard') abdominal insufflation pressures in a $2 \times 2$ factorial randomized controlled study design. Primary endpoint was the surgeon's overall satisfaction with the operating conditions, rated at end of surgery using an 11-point numerical scale. Postoperative pain scores were also evaluated.

Of 127 randomized patients, 120 had evaluable data for the primary endpoint. Overall surgical satisfaction ratings were significantly higher with deep vs. moderate NMB indicated by a least-square mean difference of 1.1 points (95% confidence interval 0.1–2.0; $P = 0.026$). Furthermore, strong

evidence of an effect was observed for standard vs. low pressure: least-square mean difference of 3.0 points (95% confidence interval 2.1–4.0; $P < 0.001$). However, no significant difference was observed in average pain scores within 24 h post-surgery for low vs. standard pressure (0.17 (95% confidence interval − 0.67–0.33); $P = 0.494$).

Although associated with significantly improved surgical conditions, the effect of a higher insufflation pressure was stronger than the one of deeper NMB. With an average of approx. 1 point on a 11-point rating scale, it also appears unlikely that such difference was of actual clinical relevance.

The difference in overall average pain score in the first 24 h after surgery was not statistically significant for either low vs. standard pressure or for deep vs. moderate NMB. No significant differences in shoulder pain were observed between the groups.

Soderstrom et.al. [13] investigated if deep compared with no NMB improved the surgical view in a study of 34 patients who were randomized in an investigator-initiated, assessor-blinded crossover design of deep vs. no NMB during laparoscopic ventral hernia repair. Deep NMB was established with rocuronium and reversed with sugammadex. Primary outcome parameter was the evaluation of surgical view assessed on a 5-point rating scale. Secondary outcomes included the surgical conditions during laparoscopic suturing of the hernia defect. There was no difference in ratings for the surgical view when comparing deep with no NMB: mean − 0.1 (95% confidence interval − 0.4 to 0.2) ($P = 0.521$, paired $t$ test). However, deep compared with no NMB improved the rating score for surgical conditions while suturing the hernia defect ($P = 0.012$). No differences were found in either total length of surgery ($P = 0.76$) or hernia suturing time ($P = 0.81$).

Deep compared with no NMB did not change the rating score of the surgical view immediately after introduction of trocars during laparoscopic ventral hernia repair, but the surgical conditions were improved during suturing of the hernia. The use of no NMB as comparator with deep block is clinically relatively meaningless as rarely 'no' block is found during the entire procedure. However, as even the worst-case scenario of 'no' block did not significantly impair the assessed parameters, it is unlikely that any differences would have been found comparing moderate vs. deep NMB.

In patients undergoing laparoscopic donor nephrectomy, two studies by Ozdemir et.al. [14, 15] investigated the effects of deep NMB.

In 2017, in a single-centre randomized controlled trial [14], 64 live kidney donors were randomly assigned to either 6 or 12 mmHg abdominal insufflation pressure. Deep NMB was used in both groups. Surgical conditions were rated on the 5-point Leiden-surgical rating scale (L-SRS), ranging from 5 (optimal) to 1 (extremely poor) conditions. If the L-SRS was too low to allow safe continuation of surgery, the intra-abdominal pressure was stepwise increased. Primary outcome parameter was the overall score on the quality of recovery-40 (QOR-40) questionnaire at postoperative day 1. The difference in the QOR-40 scores on day 1 between the low- and standard-pressure groups was not significant ($P = 0.06$). Also, the overall pain scores and analgesic consumption did not differ. Eight procedures (24%), initially commenced with low insufflation pressure, were converted to a standard pressure (>/= 10 mmHg). A L-SRS score of 5 was significantly more prevalent in the standard pressure as compared with the low-pressure group at 30 min after insufflation ($P < .01$).

The authors concluded that low-pressure pneumoperitoneum facilitated by deep neuromuscular blockade during laparoscopic donor nephrectomy neither did reduce postoperative pain scores nor did improve the quality of recovery in the early postoperative phase.

The same authors conducted another blinded randomized controlled multicentre trial in a similar setting [15]. Thirty-four live kidney donors scheduled for laparoscopic donor nephrectomy randomly received low-pressure pneumoperitoneum (6 mmHg) with either deep (PTC 1–5) or moderate NMB (TOF 0–1). In case of insufficient surgical conditions, the insufflation pressure was stepwise increased. Surgical conditions were rated by the Leiden-surgical rating scale (L-SRS) ranging from 1 (extremely poor) to 5 (optimal).

Mean surgical conditions were significantly better for patients allocated to a deep NMB (SRS 4.5 vs. 4.0; $P < 0.01$). The final insufflation pressure was 7.7 mmHg in patients with deep NMB as compared with 9.1 mmHg with moderate NMB ($P = 0.19$). The cumulative opiate consumption during the first 48 h was significantly lower in patients receiving deep NMB, while postoperative pain scores were similar. In four patients allocated to a moderate NMB, a significant intraoperative complication occurred, and in two of these patients, a conversion to an open procedure was required.

Overall, deep NMB facilitated the use of low-pressure pneumoperitoneum during laparoscopic donor nephrectomy by improving the quality of the surgical field. The high incidence of intraoperative complications reported in the study indicates that the use of low pressure with moderate NMB may compromise patient safety in this setting.

Koo. B.W. et.al. [16] examined whether maintaining deep NMB during surgery could decrease the intraoperative stress response when compared with moderate NMB in patients undergoing laparoscopic gastrectomy.

The primary outcome variable was the postoperative blood level of interleukin-6, and the secondary outcome variables were intraoperative or postoperative blood levels of tumour necrosis factor-α, interleukin-1β, interleukin-8 and C-reactive protein. A total of 96 patients were recruited and 88 (44 in each group) were included in the analyses. The levels of tumour necrosis factor-α and interleukin-1β measured at the end of surgery, interleukin-6 and interleukin-8 measured at 2 h postoperatively and C-reactive protein measured at 48 h postoperatively were all significantly increased compared

with the preoperative values, but there were no differences between the moderate and deep NMB groups.

The authors hypothesized that improving the surgical conditions by maintaining intraoperative deep NMB may reduce related tissue damage and thereby reduce intraoperative and postoperative inflammatory mediators and acute-phase reactant release.

The authors found improved surgical conditions, both by means of a decreased incidence of spontaneous breathing and/or decreased requests for additional NMBA doses by the surgeons. However, no differences in the levels of cytokines or C-reactive protein between deep and moderate NMB groups were detected.

## Deep NMB in Non-laparoscopic Surgical Procedures Since 2017

**Summary** There is an overall paucity of studies on NMB in non-laparoscopic procedures. However, all available data suggests that deep NMB significantly improved surgical conditions and also facilitated the safe administration of anaesthesia by improving lung compliance. One study reported a reduced opioid consumption after deep vs. no NMB.

### Individual Studies

Madsen et.al. [17•] conducted a double-blinded, randomized study including a total of 128 patients undergoing elective upper laparotomy. Patients were randomized to either continuous deep NMB (infusion of rocuronium 2 mg $ml^{-1}$) or standard NMB (bolus of rocuronium 10 mg or increased depth of anaesthesia). Surgical conditions were evaluated using a 5-point subjective rating scale (1, extremely poor to 5, optimal) every 30 min. Primary outcome parameter was the mean score of operating conditions. Other outcomes were surgical rating scores during closure of the fascia, the need for rescue medication in case of poor operating conditions and the incidence of wound dehiscence and infection.

Deep compared with standard NMB resulted in better ratings of surgical conditions, median 4.75 (range 3–5) vs. 4.00 (range 1–5) ($P < 0.001$), respectively. Deep vs. standard NMB also resulted in better ratings of surgical conditions during closure of the fascia ($P < 0.001$), fewer episodes of need to optimize surgical conditions ($P < 0.001$) and a lower incidence of sudden movements ($P < 0.001$). However, no differences in operating time, occurrence of wound infection and wound dehiscence were detected. Thirty-one (49%) patients receiving standard NMB but only 11 (17%) of patients with deep NMB needed an anaesthetic intervention (bolus of NMBA or increased depth of anaesthesia) to allow safe continuation of surgery.

Casanova et.al. [18] published the results of a longitudinal observational trial in 76 patients undergoing lung resection surgery requiring one-lung ventilation in lateral decubitus position. Ventilator data and hemodynamic parameters were registered at time points of different depth of NMB (intense, deep and moderate blockade). Peak, plateau and mean airway pressures were significantly lower during intense and deep NMB and both compliance and peripheral oxygen saturation were significantly higher. The authors concluded that deep NMB may improve poor lung mechanics frequently observed during one-lung ventilation.

A multicentre randomized parallel intervention trial by Laosuwan et.al. [19] investigated deep vs. moderate NMB in 102 patients undergoing endolaryngeal surgery.

One hundred and two patients underwent microscopic endolaryngeal surgery at four university hospitals. Paralyzed with rocuronium, all patients were randomized into moderate NMB (TOF 1–2) (M group) or deep NMB (PTC 1–2) (D group). Operating conditions were evaluated as primary outcome parameter.

Clinically acceptable conditions were observed in all 49 patients (100%) of the D group and 43 patients (89.6%) in the M group ($P = 0.027$). The frequency of notable vocal cord movement in the M group was significantly higher than the D group (70.8% vs. 32.7%). Patients in the M group required more additional doses of rocuronium (47.9%) than the D group (20.4%) to maintain clinically required full relaxation ($P = 0.005$).

Oh S.K. et al. [20] conducted a prospective randomized controlled trial in 83 patients comparing deep NMB ($n = 43$) vs. no NMB ($n = 40$) in lumbar fusion surgery. In the deep NMB group, rocuronium was administered to maintain deep block until the end of surgery. In the no NMB group, sugammadex 4 mg $kg^{-1}$ was administered to reverse NMB 10 min after tracheal intubation and patient positioning.

Peak and plateau inspiratory airway pressures, as well as wound retractor pressure, were significantly lower in the deep NMB group than in the no NMB group (18.4 ± 1.1 vs. 20.2 ± 1.1, 17.1 ± 1.4 vs. 19.4 ± 1.1 cmH2O and 81.2 ± 9.1 vs. 100.0 ± 7.3 mmHg, respectively) ($P < 0.001$). The operating conditions and overall surgical satisfaction score (8.0 ± 1.3 vs. 3.1 ± 1.2; $P < 0.001$) were superior in the deep NMB group. Rescue rocuronium consumption was significantly higher in no vs. deep NMB (15.1 ± 9.4 vs. 0.6 ± 1.6 mg; $P < 0.001$). Throughout surgery, five patients in the deep NMB group received a single injection of rescue rocuronium (5 mg), while in the no NMB group, 37 patients received 1–7 rescue rocuronium injections (5–35 mg). The average infusion rate of propofol was significantly lower in the deep NMB group (0.104 ± 0.014 vs. 0.113 ± 0.015 mg $kg^{-1}$ $min^{-1}$; $P < 0.001$), but no difference in the average infusion rate of remifentanil was found.

Pain scores in PACU assessed via a numerical rating scale (0–10) showed lower pain scores after deep NMB ($P < 0.01$). The fentanyl consumption in PACU was 31.4 ± 24.4 mcg after deep NMB vs. 86.3 ± 29.9 mcg after no NMB ($P < 0.001$). The length of stay in PACU was significantly shorter (61.9 ± 5.9 vs. 87.0 ± 24.5 min; $P < 0.001$) and the incidence of adverse events in PACU (0/43 vs. 8/32; $P = 0.002$) was lower after deep NMB.

## Conclusion

With a high number of prospective randomized trials and the increased use of clinically meaningful comparators (moderate vs. deep NMB as opposed to no vs. deep block), the overall quality of related studies has improved within the last years.

There appears to be sufficient evidence for improved surgical conditions after deep vs. moderate NMB in both laparoscopic and non-laparoscopic procedures. Though the mean differences in the surgical field ratings between the groups have frequently found to be modest at best, it is of note that poor conditions were often more likely in moderate NMB. Poor operating conditions have been clearly linked to an unfavourably increase in post-surgical complications. In open surgery, deep NMB appears to improve lung compliance and may hence facilitate the administration of safe general anaesthesia.

However, deep block cannot always guarantee adequate operating conditions with low-pressure pneumoperitoneum, and in some studies, higher insufflation pressures resulted in better conditions when compared with deep block.

A clear link between deep NMB and postoperative patient outcome is still missing, and outcomes such as the quality of recovery or postoperative pain are still controversially discussed. No study in this review reported rocuronium- or sugammadex-related significant side effects. However, though such adverse effects are known to be overall rare, the residual risk vs. benefit should be considered when making decisions about the depth of NMB. As so often, no single intervention replaces good surgeon-anaesthesiologist teamwork.

### Compliance with Ethical Standards

**Conflict of Interest** Thomas Ledowski has received speaker honoraria as well as travel grants from Merck & Co. However, neither aforementioned company nor any other third party had any influence on this review. Rohit Jain declares no conflict of interest.

**Human and Animal Rights and Informed Consent** This review does not reference studies performed by either of the authors.

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Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance


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