Sugammadex sodium is a modified \( \gamma \)-cyclodextrin with a very high affinity for rocuronium and, to a lesser extent, vecuronium molecules. In vivo administration results in immediate encapsulation of rocuronium and vecuronium, resulting in termination of neuromuscular blockade, usually within 3 minutes. This new neuromuscular blocking agent is specific for the aminosteroidal neuromuscular blocking agents rocuronium and vecuronium. Experience gained through worldwide clinical use of sugammadex offers US anesthesia providers the opportunity to better understand this new drug and its clinical applications. The seminal and current literature concerning clinical use of sugammadex is reviewed, and considerations for its incorporation into practice are provided.

**Keywords:** Blocking agent, in vivo administration, sugammadex.

Research scientists at Organon International (Oss, the Netherlands) developed sugammadex sodium during the 1990s. The drug was originally conceived as a solubilizing agent for rocuronium, but synthesis of multiple analogues produced a supramolecule that had extremely high encapsulation binding capacity to the rocuronium and vecuronium molecules. The attractions of sugammadex for rocuronium and vecuronium are multiple noncovalent thermodynamic bindings that in aggregate result in an essentially permanent inclusion complex and prevent further attachment of the neuromuscular blocking agents (NMBA) to acetylcholine (ACh) receptors. This inclusion complex of rocuronium or vecuronium encapsulated in sugammadex (1:1 ratio) occurs primarily in the bloodstream. Rapid encapsulation of NMBA molecules establishes a concentration gradient that extracts additional NMBA molecules from the nicotinic motor junction into the plasma compartment to permit their encapsulation as well. The average dose-dependent time from intravenous administration to full reversal of motor blockade is 3 minutes. Direct encapsulation of rocuronium and vecuronium terminates neuromuscular blockade (NMB) and fully restores motor function. Conventional reversal agents that act indirectly as cholinesterase inhibitors do not inactivate NMBA ability to attach to ACh receptors; nor do they offer complete reversal of NMB (Figure).

European, Asian, and Central and South American countries have previously approved sugammadex sodium (Bridion) for clinical use. Approval in the United States has been delayed pending more clinical trials that were recently completed and submitted to the Food and Drug Administration (FDA). Therefore, the experience with sugammadex by anesthesia clinicians worldwide offers the opportunity for practitioners in the United States to glean additional insight and understanding, as well as the ability to critique its application to clinical practice. Peer-reviewed literature published after approval for clinical practice in other countries was retrieved from multiple databases, including PubMed, Google Scholar, and individual journal websites. Although a formal systematic approach was not conducted, searches were repeated frequently, and cross-referencing of existing sources was done to ensure that a thorough representation of available clinical applications was available for review. An ongoing continual web search strategy using the Google Scholar Alert system and the keyword sugammadex was started in 2008 to follow any new developments and was continued until publication submission in spring 2015. The following narrative review offers considerations for the application of sugammadex to clinical practice based largely on clinical case reports.

**Sugammadex Comparison With Neostigmine**

The most straightforward consideration is the comparison of sugammadex with neostigmine for reversal of NMB. Clinical trials have appropriately focused heavily on this direct comparison. A Cochrane systematic review by Abrishami et al. presents these clinical comparisons in aggregate. Systematic reviews offer high-quality evidence for guiding clinical practice. Abrishami and colleagues concluded: “Sugammadex was shown to be more effective than placebo (no medication) or neostigmine in reversing muscle relaxation caused by [rocuronium-induced] neuromuscular blockade during surgery and is relatively safe.” Sugammadex also effectively reversed...
all levels of NMB, including profound block, faster than did neostigmine or placebo. In 18 clinical trials of 1,321 subjects, the overall incidence of adverse events was less than 1%.

Reinducing Neuromuscular Blockade After Sugammadex Administration

After reversal by sugammadex, immediate reestablishment of NMB with an aminosteroidal NMB agent is difficult. It would require a very large dose to occupy all sugammadex molecules before the remaining NMBA molecules are able to diffuse to the motor junction and attach to the nicotinic ACh receptors. Reparalysis with aminosteroidal NMBAAs after sugammadex-induced reversal is possible but is probably neither advised nor necessary. The specificity of sugammadex for the aminosteroidal NMBAAs rocuronium and vecuronium allows unimpeded reestablishment of NMB with isoquinoline NMBAAs (atracurium, cisatracurium and mivacurium). The isoquinoline NMBAAs and succinylcholine remain fully effective at recommended doses. Conventional reversal or spontaneous recovery of motor function must be considered after the use of isoquinoline NMB and succinylcholine. In the unusual circumstance where reestablishment of NMB with an aminosteroidal NMB might be required, the elimination time of sugammadex should be considered.

Special Patient Populations

• Renal Disease. Patients affected by renal disease will have decreased elimination of sugammadex and its inclusion complex. In people with normal renal function, the plasma concentration of sugammadex falls to approximately 0.5 µg/mL in 8 hours. The median time required to achieve a similar plasma level in patients with renal failure (creatinine clearance below 30 mL/min) was 48 hours or more. The same study found that high-flux dialysis was effective at removing sugammadex from the plasma, but low-flux dialysis was not. This is consistent with results of clinical studies that also found high-flux, but not low-flux, dialysis was effective at removing sugammadex from the plasma. High-flux dialysis uses larger pore size in its dialyzing membranes. High-flux dialysis is currently the most common method of therapy in the world. Considering that low-flux dialysis membranes are effective at diffusing only small molecules less than 500 Da in molecular weight, it is understandable that sugammadex, which exceeds 2,000 Da, will be difficult to remove. High-flux membranes and newer protein-permeable membranes have pore sizes that more easily allow midsized (500-40,000 Da) and larger molecules to pass. It is possible to use sugammadex in patients with renal insufficiency and failure, with the expectation of its removal later at the time of dialysis. The effect of long-duration, in vivo dwell times for the sugammadex-rocuronium inclusion complex has not been determined. Although the sugammadex binding is essentially permanent, definitive safety and efficacy in patients with severe renal insufficiency is undetermined. Prescribing information should be followed regarding sugammadex use in

Figure. Encapsulation of Rocuronium Showing Carboxyl Thioether Extensions on Base Cyclodextrin Molecule

Note: Eight extensions are present on sugammadex, but only two are shown. Binding attractions of sugammadex occur in the cyclodextrin cavity and between the positive ammonium and the negative hydroxyl groups, causing a near-permanent inclusion complex.
patients with renal insufficiency and failure.

**Hepatic Disease.** Sugammadex is excreted intact and entirely by the renal system. No hepatic metabolism occurs. There are no known metabolic byproducts or microsomal enzyme alterations. No restrictions have been found regarding sugammadex use in patients with liver disease or those undergoing hepatic surgery. A longer duration and greater variability of sugammadex-induced reversal of rocuronium was noted (4-14 minutes using 2 mg/kg from train-of-four [TOF] 2/4 ) in a study of 13 consecutive patients with end-stage liver disease undergoing orthotopic liver transplantation. The cause of this deviation from the usual rapid reversal of rocuronium by sugammadex is unknown. Additional understanding is needed of potential altered sugammadex pharmacokinetics associated with hepatic disease and transplantation.

**Cardiac Disease.** The use of sugammadex in patients with cardiac disease has been explored in clinical studies and found to be safe and efficacious. Sugammadex does not alter hemodynamics, as cholinesterase inhibitors and anticholinergics can. This is especially beneficial when considering patients with heart failure. Cammu et al explored hemodynamic stability associated with sugammadex-induced reversal in 12 patients with an ejection fraction less than or equal to 25% and found that hemodynamic stability was maintained with sugammadex-induced reversal. The time to full reversal was slightly increased, likely because of slower circulation times leading to delayed distribution of the sugammadex molecules in the plasma compartment.

Sugammadex does not prolong QT interval.

Older literature described possible QT prolongation associated with sugammadex. We now understand that this prolongation was associated with sevoflurane and other known QT prolongation precipitators. One case report discussed atrioventricular block occurrence at the time of surgical infiltration of local anesthetic and sugammadex administration. Six milliliters of 1% lidocaine with epinephrine at a concentration of 1:200,000 was administered after facial surgery and then immediately before administration of sugammadex. Atrioventricular block ensued, which spontaneously converted to normal sinus rhythm within minutes. No causative relationship has been established regarding sugammadex and conduction abnormalities. Local anesthetics, however, are known to precipitate conduction alterations.

Sugammadex has been successfully and repeatedly used in a patient with known cardiac conduction abnormalities, Brugada syndrome.

Brugada syndrome is "characterized by an ST-segment elevation in the right precordial [electrocardiogram] leads and a high incidence of sudden death in patients with structurally normal hearts." Succinylcholine and neostigmine are contraindicated in these patients, as these agents may cause ventricular fibrillation. The use of sugammadex allowed for necessary NMB for electroconvulsive therapy (ECT) in this particular patient while avoiding 2 other contraindicated drugs that may have been otherwise considered.

**Pulmonary Disease.** Clinical studies have found no negative sequelae associated with sugammadex use in patients with pulmonary disease or lung surgery. The ability of sugammadex to fully restore muscle strength after NMB offers patients with pulmonary disease and respiratory compromise the optimal opportunity to successfully wean from mechanical ventilation and be extubated. Procedures requiring deep NMB that ensures no movement such as rigid bronchoscopy may also benefit from nondepolarizing NMB with immediate reversal by sugammadex. There are times when the anesthesia provider receives little advance notice of the end of a surgical procedure. Cholinesterase inhibitors require a degree of spontaneous recovery, preferably a TOF count of 3/4. As opposed to traditionally used agents, sugammadex may be administered at any time and depth of NMB, allowing exact timing of NMB and reversal.

**Neuromuscular Diseases.** Sugammadex has been found to be beneficial in cases of neuromuscular diseases that previously would have required continued postoperative intubation or the avoidance of NMB. The most extensive and impressive cases are those that involve myasthenia gravis (MG). An autoimmune disease that decreases nicotinic ACh receptors, MG is manifest as muscle weakness and fatigability. Currently, patients with MG of greater than 6-year duration, requiring a treatment dose of pyridostigmine greater than 750 mg, have a coexisting pulmonary disease such as chronic obstructive pulmonary disease, and a vital capacity of 2.9 L or less will likely remain intubated postoperatively. Several case reports of successful NMB reversal with sugammadex in patients with MG may render these predictive criteria unnecessary. These reports reflect the ability to use select NMBAs in these patients with a full return to baseline motor function. This return to baseline motor function in patients with MG optimizes the potential for extubation. With sugammadex, residual paralysis/relaxation (even minimal degrees reflected by T1/T4 above 0.7 and below 1.0) should not be a factor to determine extubatability. The avoidance of cholinesterase inhibitors for reversal will also eliminate the potential drug-drug interaction with orally administered cholinesterase inhibitors used to treat their MG, which can cause cholinergic crisis.

Considering the likelihood of some degree of residual weakness after NMB reversal with cholinesterase inhibitors, sugammadex appears to be a better choice in patients with underlying muscle weakness due to atrophy or impaired nerve transmission. This clinical rationale was applied to patients with other neuromuscular diseases, including Duchenne, myotonic dystrophies, transverse myelitis, amyotrophic lateral sclerosis.
(ALS), and Huntington disease. The required use of rocuronium in a patient with spinal muscular atrophy also had NMB effectively reversed with sugammadex allowing for extubation. Similar NMB reversal and extubation using sugammadex was accomplished in a 38-week primigravida, wheelchair-bound patient because of transverse myelitis. This patient presented for elective cesarean section and underwent a general anesthetic with a rapid sequence induction using rocuronium, 1.2 mg/kg. After 3.25 hours, NMB was still present despite neostigmine reversal attempt, sugammadex (4 mg/kg) was used to fully reverse and successfully allow extubation of the patient.

Other disease processes that exhibit muscle weakness and loss of coordination are ALS (also called Lou Gehrig disease) and Huntington disease. ALS is a degenerative disease of both upper and lower motor neurons. Progressive loss of motor function causes severe difficulty in movement, swallowing, and breathing. The importance of this lessened ability to breathe is shown in a case report in which a 47-year-old man with ALS was unable to be extubated after a surgical repair of a humeral fracture despite a return to a TOF ratio of 0.9. Although a TOF ratio of 0.9 is considered “full reversal,” the baseline weakened status of some patients makes this missing 10% function necessary to adequately ventilate spontaneously. In this case, sugammadex, 2 mg/kg, restored all baseline motor function and allowed extubation to proceed within minutes. Another case involved Huntington’s disease, a neurodegenerative disorder that results in progressive cognitive and motor dysfunction hallmarked by rapid and jerky (choreiform) movements. Dysphagia puts these patients at risk of aspiration. Clinical decision making regarding weakened airway protective motor function, possible side effects of succinylcholine, potential neostigmine exacerbation of choreiform movements, and potential residual paralysis in this patient type is aided by the availability of sugammadex. A 60-year-old, 61-kg female patient with Huntington disease requiring general anesthesia for a thyroid lobectomy successfully underwent modified rapid sequence intubation with rocuronium, which was reversed with sugammadex intraoperatively to enable surgical electromyographic (EMG) monitoring.

If NMB is needed in patient populations with neuromuscular diseases, the use of rocuronium with sugammadex-induced reversal should be given serious consideration. The concerns of aspiration risk, sensitivity to NMBA effects, and potential for required postoperative intubation and ventilation may be mitigated by restoration of baseline motor function. Additionally, upregulation of ACh receptors that may occur in these patient populations necessitates the avoidance of succinylcholine because of the risk of hyperkalemia. Sugammadex allows the nondepolarizing NMBA rocuronium to be used for rapid sequence intubation, as reversal of NMB may be accomplished after 3 minutes. The case reports described here represent effective rocuronium reversal. Although sugammadex reverses vecuronium, its greater affinity for rocuronium provides a greater assurance of complete reversal. Sugammadex-induced reversal of rocuronium offers another alternative to restriction of NMBA and/or continued postoperative mechanical ventilation in this patient population.

• Elderly Patients and Pediatric Patients. Clinical trials exploring sugammadex use in elderly patients found effective reversal of NMB, with a slight but significant delay until full reversal attributed to a slower circulation time. Considering the associated morbidity of the elderly patient, sugammadex use in specific disease states discussed in this review may offer some guidance for its use in this patient population. Pediatric populations have not been extensively studied in clinical trials, and a current recommendation for sugammadex outside the United States is only for routine reversal at TOF 2/4 for children. A particularly interesting case report describes the successful use of sugammadex to reverse rocuronium-induced NMB in a 12-year-old patient with mild, early-onset MG undergoing a thymectomy.

• Patients With Obesity and Obstructive Sleep Apnea. With proper dosing, sugammadex quickly and effectively reverses NMB in obese patients. The advantage of sugammadex to achieve 100% full and complete reversal places this drug in a preferable position when considering the associated comorbidities of obesity. Obstructive sleep apnea has a high incidence in the obese population. Any degree of residual paralysis can impair breathing mechanics. Neostigmine reversal in patients with obstructive sleep apnea may actually be less effective than sugammadex for 2 reasons: indirect and incomplete reversal of NMB and by direct airway dilator muscle impairment. Recent work by Eikermann et al shows neostigmine contributing to the impairment of pharyngeal dilator muscles in rats even while improving peripheral muscle function after NMB. Use of recommended sugammadex doses for reversal of NMB in obese patients is a prudent consideration.

Sugammadex dosing recommendations (Table) are based on total body weight. Different opinions regarding dosing in obese patients center on total body weight vs lean body weight or ideal body weight. Ideal body weights are compiled tables of desirable weights based on gender and height correlates that have little or no...
application to direct patient-specific dose calculations. Many current anesthetic drugs are appropriately based on lean body weight. With NMBAs and sugammadex, weight-based dosing would be expected to focus on lean body weight, as it is the targeted muscle compartment. Forbes and Welle31 found that lean body mass actually increases along with increasing body weight in obesity. This can create some difficulty in estimating lean body weight and appropriate dosing for the obese. It is unlikely that practitioners do formal body weight calculations32:

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### Table. Sugammadex Dosing Recommendations

<table>
<thead>
<tr>
<th>Train-of-four count</th>
<th>Posttetanic count</th>
<th>Sugammadex dose, mg/kg</th>
</tr>
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<tbody>
<tr>
<td>2/4</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>0/4</td>
<td>1-2</td>
<td>4</td>
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If one follows actual body weight dosing schedules, it is possible that the patient would receive more sugammadex than needed. Although high-dose sugammadex (up to 96 mg/kg) has been found to be safe and efficacious,33 minimizing cost by minimizing dose has been considered.

Conversely, the risk with underdosing sugammadex (eg, basing dose on ideal body weight) is incomplete reversal of NMB. This underdosing was found in 120 morbidly obese patients in whom ideal body weight was used to dose sugammadex.34 Van Lancker et al35 sought to identify an optimal dosing schedule that corrects for the discrepancy in morbid obesity between lean and actual body weight. In a double-blinded, randomized, controlled trial 100 morbidly obese patients undergoing laparoscopic bariatric surgery under propofol anesthesia were found to be adequately reversed from TOF 1/4 to 2/4 to a TOF ratio greater than 0.9 with 2 mg/kg of sugammadex based on ideal body weight plus 40%.35 This study attempted to develop a quick method that would essentially estimate a lean body weight dose of sugammadex for the morbidly obese patient. All patients in their study were found to have successful reversal. However, a correspondence by Sabaté36 appropriately states the limits of this study: “Because the authors did not include information on the total dose of rocuronium, the duration of surgery, or slow responders to sugammadex, we are unable to draw conclusions on the correct [ideal body weight]-based dose”.

Another case report reflects the potential to underdose obese patients at even slightly lower-than-recommended doses (1.74 mg/kg vs 2 mg/kg) of sugammadex based on actual body weight. A 54-year-old woman underwent general anesthesia for laparoscopic repair of an abdominal dehiscence.37 Rocuronium (total, 170 mg) was administered during the case, and a TOF 2/4 at the adductor pollicis muscle was present before reversal by sugammadex. Within 5 minutes of sugammadex-induced reversal, a TOF ratio of 0.9 was present, reflecting full reversal, and the patient was successfully extubated. Ten minutes later in the recovery room the patient displayed residual paralysis with respiratory failure (repeated TOF, 1/4). An additional 200 mg of sugammadex successfully reversed this residual paralysis.37

Interindividual variability to sugammadex doses exists; thus, decreasing the recommended sugammadex doses that dose-finding studies have identified risks incomplete reversal and recurarization. This potential for incomplete reversal and recurrence of NMB was identified in clinical trials1 and remains a present concern with any decreasing of recommended doses. Sugammadex dosing on actual body weight is recommended.

### Obstetric Patients

Sugammadex use in obstetric patients has also successfully reversed NMB, but the data regarding the teratogenicity and safety of sugammadex in pregnant women are limited. No reported teratogenicity has been found. The data on the safety of sugammadex are being reported here entirely based on case reports. Case studies of elective cesarean deliveries came from Germany, where 0.6 mg/kg of rocuronium was administered and then reversed with sugammadex at a concentration of 2 to 4 mg/kg and achieved full reversal in 2 minutes.38 In Japan, rocuronium, 0.9 mg/kg, was administered and was effectively reversed with sugammadex, 2 mg/kg, within 2 minutes.39 These case reports found safe and effective use of sugammadex for elective cesarean deliveries. An emergency cesarean delivery reported from Columbia in which rocuronium was administered at a dose of 0.6 mg/kg and reversed with sugammadex, 1 mg/kg (lower than the recommended dose), also noted full reversal within 2 minutes with no negative effects.40 In an elective but complicated cesarean delivery, a wheelchair-bound woman with transverse myelitis from Ireland received rocuronium, 1.2 mg/kg, and then received sugammadex, 4 mg/kg, with full reversal within 2 minutes.23

All these case studies described have used the N MBA rocuronium, 0.6 to 1.2 mg/kg, with reversal by sugammadex using doses of 1 to 4 mg/kg. Complete reversal within 2 minutes without signs of recurrence of NMB or residual muscle weakness was noted in all cases, without negative sequelae. These case reports provide limited but useful data regarding the safety and efficacy of sugammadex as a rocuronium reversal agent when employed in women requiring elective or emergent cesarean delivery. The limited availability of full-scale studies precludes specific guidance for its use in this patient population.
Special Situations

- **Difficult Airway.** The difficult airway presents multiple considerations, including establishing manual ventilation, technique for securing airway patency, choice of NMBA, and extubation preparedness. Concerns at the times of intubation and extubation require prudent choices.

- **Rapid Sequence Intubation and “The Can’t Intubate, Can’t Ventilate” Scenario.** Sugammadex could change the way a routine rapid sequence induction is performed. Rapid sequence induction is done for a patient with a full stomach or at risk of aspiration. Normally this is accomplished by an intravenous bolus of propofol or etomidate followed by succinylcholine as the NMBA. Succinylcholine is often chosen because of its fast onset and short duration of action. The fast onset allows the intubation to be accomplished quickly, minimizing the exposure of the airway to possible aspiration of stomach contents. The short duration is also advantageous for return of spontaneous ventilation and return of protective airway reflexes before excessive or prolonged hypoxia ensues in the “can’t intubate, can’t ventilate” scenario. A short duration of action is also desirable for short surgical procedures.

Succinylcholine, unfortunately, has many potential side effects, including arrhythmias; hyperkalemia; increased ocular, gastric, and intracranial pressure; myalgia, masseter spasm, and the potential to trigger malignant hyperthermia. These side effects make the use of succinylcholine undesirable in certain clinical situations. Rocuronium is commonly used as an NMBA instead of succinylcholine. Doses in the range of 0.9 mg/kg to 1.2 mg/kg have onset times similar to succinylcholine, allowing rapid intubation. The clinical duration of the higher doses is substantially longer, in the range of 60 to 70 minutes. The use of sugammadex for rapid reversal would be a solution to the long duration dilemma of a rapid sequence induction using rocuronium instead of succinylcholine. According to the manufacturer’s information, sugammadex, 16 mg/kg, given 3 minutes after a rocuronium dose of 1.2 mg/kg had a mean time to recovery of T1 to 90% and a return of the T1 to T4 ratio to 0.9 faster than the spontaneous recovery of succinylcholine.30 The reversal of a profound high-dose rocuronium-induced NMB with sugammadex is faster than spontaneous recovery from succinylcholine (3 minutes vs 7-10 minutes).1 The ability to reverse the NMBA quickly and completely would address the paralysis component of the “can’t intubate, can’t ventilate” scenario but not the anesthetic induction effects, which will remain for a given amount of time. Restoration of motor function will not ensure return of ventilation or ability to mask ventilate. Although these findings may support rocuronium as the paralytic drug of choice for rapid sequence intubation, preparation for securing the airway must remain in the forefront.

- **Extubation and Postoperative Recovery.** The ratio-
motor function and better reflects a patient’s true baseline so that subsequent early mild suppressions may go unnoticed, a false assumption of true normal patient-specific values. Conduction disturbances. Weakened baseline values risk obtaining a true evaluation of baseline motor function. Inhibitors or relying on spontaneous recovery may hinder neurophysiologic monitoring. The use of cholinesterase inhibitors or reversal with cholinesterase inhibitors before intubation is common in these patients. Clinical practice has been to allow spontaneous recovery of motor function. The ability of sugammadex to quickly restore neuromuscular conduction allows the use of rocuronium or vecuronium before neurophysiologic monitoring. This application of sugammadex has been successfully used for patients requiring neurophysiologic monitoring during brain and spinal cord surgeries. The initial use of nondepolarizing NMBAs during induction and intubation is common in these patients. Clinical practice has been to allow spontaneous recovery of motor function or reversal with cholinesterase inhibitors before neurophysiologic monitoring. The use of cholinesterase inhibitors or relying on spontaneous recovery may hinder obtaining a true evaluation of baseline motor function. Baseline motor function allows reliable comparison with intraoperative events and appropriate identification of conduction disturbances. Weakened baseline values risk a false assumption of true normal patient-specific values so that subsequent early mild suppressions may go unnoticed. Sugammadex-induced reversal of NMB restores full motor function and better reflects a patient’s true baseline motor evoked potentials (MEPs). This has been confirmed in a study of 47 patients that compared MEPs both before and after sugammadex administration during cases requiring neurophysiologic monitoring. This application of sugammadex is worthy of further exploration. In an attempt to address this need, Sloan conducted a review of NMB along with neuromuscular monitoring. This review found that with EMG and MEP neurophysiologic monitoring, waveform amplitudes are decreased but can still be conducted with NMB maintained at TOF 2/4 at the ulnar nerve. Cranial nerve monitoring requires less NMB. The use of sugammadex in patients requiring neurophysiologic monitoring may establish better motor function for cranial nerve monitoring but is not absolutely needed for EMG or MEP monitoring. Somatosensory evoked potentials (SSEP) are not affected by NMB. Neurophysiologic monitoring of afferent pathways may be conducted with low-level NMB, but efferent pathways require greater motor function.

**Potential for Movement and Elevated Cerebral Activity Monitor Values (BIS, Entropy).** The potential for immediate patient movement after sugammadex was identified in clinical trials and discussed in reviews. Administering sugammadex after weaning anesthetic depth toward the end of a procedure risks the potential to unmask light anesthesia and promote patient movement and withdrawal. Reversal only after the conclusion of surgical or diagnostic procedures can prevent this intraoperative movement. The rapid onset and fast full reversal caused by sugammadex negate the early reversal needed to compensate for the slow onset of cholinesterase inhibitors. Although sugammadex has no effect on depth of amnesia or analgesia, there has been documentation of elevated bispectral index (BIS) and Entropy (GE Healthcare) indexes but not concurrent electroencephalographic measurements. The likely cause of these elevated numerical values is EMG activity. Increased motor activity is reflected by the BIS EMG and Response Entropy values. This increased EMG activity does not reflect consciousness but rather the reestablished motor activity enabled by sugammadex. Maintaining deeper levels of NMB until the conclusion of surgery may mask light anesthesia and awareness that would have been suggested by patient movement. Cognizance of depth of anesthesia is paramount.

**Neurophysiologic Monitoring**

The ability of sugammadex to quickly restore neuromuscular conduction allows the use of rocuronium or vecuronium before neurophysiologic monitoring. This application of sugammadex has been successfully used for patients requiring neurophysiologic monitoring during brain and spinal cord surgeries. The initial use of nondepolarizing NMBAs during induction and intubation is common in these patients. Clinical practice has been to allow spontaneous recovery of motor function or reversal with cholinesterase inhibitors before neurophysiologic monitoring. The use of cholinesterase inhibitors or relying on spontaneous recovery may hinder obtaining a true evaluation of baseline motor function. Baseline motor function allows reliable comparison with intraoperative events and appropriate identification of conduction disturbances. Weakened baseline values risk a false assumption of true normal patient-specific values so that subsequent early mild suppressions may go unnoticed. Sugammadex-induced reversal of NMB restores full motor function and better reflects a patient’s true baseline motor evoked potentials (MEPs). This has been confirmed in a study of 47 patients that compared MEPs both before and after sugammadex administration during cases requiring neurophysiologic monitoring. This application of sugammadex is worthy of further exploration. In an attempt to address this need, Sloan conducted a review of NMB along with neuromuscular monitoring. This review found that with EMG and MEP neurophysiologic monitoring, waveform amplitudes are decreased but can still be conducted with NMB maintained at TOF 2/4 at the ulnar nerve. Cranial nerve monitoring requires less NMB. The use of sugammadex in patients requiring neurophysiologic monitoring may establish better motor function for cranial nerve monitoring but is not absolutely needed for EMG or MEP monitoring. Somatosensory evoked potentials (SSEP) are not affected by NMB. Neurophysiologic monitoring of afferent pathways may be conducted with low-level NMB, but efferent pathways require greater motor function.

**Electroconvulsive Therapy**

Electroconvulsive therapy has also been successfully conducted using rocuronium and sugammadex. The immediate reversal of rocuronium by sugammadex permits the avoidance of succinylcholine side effects while still able to relax the patient’s musculature with a nondepolarizer during ECT to protect against muscle and bone injury during the induced seizure activity.

**Malignant Hyperthermia**

Concerns associated with the use of succinylcholine in patients with malignant hyperthermia (MH) and, to a lesser extent, neuroleptic malignant syndrome (NMS), also known as neuroleptic hyperthermia, require the avoidance of this triggering agent. Succinylcholine is absolutely contraindicated in cases of known or suspected MH-susceptible patients. The loose association of succinylcholine to NMS has caused some to avoid its use, at least until a definitive diagnosis of the underlying syndrome is made. NMS differs from MH in that it is a central, not peripheral, metabolic dysfunction. NMS is triggered by antipsychotic medications. Both syndromes are characterized by elevated temperature, muscle rigidity, and autonomic dysfunction. Patients experiencing NMS will respond to nondepolarizing NMBAs, whereas MH will not. In cases of suspected or known NMS, nondepolarizing NMB use is preferable, especially if sugammadex is available to immediately reverse if needed.

**Conclusion**

The clinical use of sugammadex has shown numerous applications and improvements for practice. Without a doubt, reversal of NMB is faster and more complete with sugammadex compared with cholinesterase inhibitors. Although cholinesterase inhibitors have been successfully used for patients requiring neurophysiologic monitoring, waveform amplitudes are decreased but can still be conducted with NMB maintained at TOF 2/4 at the ulnar nerve. Cranial nerve monitoring requires less NMB. The use of sugammadex in patients requiring neurophysiologic monitoring may establish better motor function for cranial nerve monitoring but is not absolutely needed for EMG or MEP monitoring. Somatosensory evoked potentials (SSEP) are not affected by NMB. Neurophysiologic monitoring of afferent pathways may be conducted with low-level NMB, but efferent pathways require greater motor function.
used for more than 50 years, sugammadex offers quicker and more complete reversal of aminosteroidal NMBA-induced NMB of all depths, with minimal side effects. Practice improvement can be surmised from reports of sugammadex use in patients with renal, hepatic, cardiac, pulmonary, and neuromuscular diseases; in elderly, obstetric, and obese patients; and in clinical situations that include “can’t intubate, can’t ventilate,” rescue of residual NMB, and the use of rocuronium to avoid succinylcholine. The full benefits to be derived from this drug lie in the decision-making processes of clinicians, the specific patient populations, and the clinical scenario for which it may be applied. Sugammadex offers more clinical choice for not only NMBA reversal but also the freedom to reverse from any depth of NMB. Increased control of NMB reversal encourages a more thorough measurement of the degree of NMB. Neuromuscular monitoring is a practice for which sugammadex may promote reciprocal advances.

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