Reversal of profound rocuronium block monitored in three muscle groups with sugammadex in ponies

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Key points
- Recovery from neuromuscular block is a clinical problem in horses/ponies.
- Sugammadex reversed profound rocuronium block in 4 min in ponies.
- Direct stimulation of the radial nerve can be used to monitor neuromuscular block in horses/ponies.

Background. This clinical study evaluated the speed of reversal of profound rocuronium block in ponies using sugammadex and investigated the differences in onset and recovery from block in three different muscle groups.

Methods. Anaesthesia was induced and maintained with isoflurane in oxygen 100% in eight ponies. Neuromuscular monitoring was performed at each site using acceleromyography: in the extensor muscles of the pelvic limb (peroneal nerve) and thoracic limb (radial nerve), and in the orbicularis oris muscle (OOM; facial nerve). Rocuronium 0.6 mg kg\(^{-1}\) i.v. was administered, followed 5 min later by sugammadex 4 mg kg\(^{-1}\) i.v. Onset time (onsetROC), maximum block, and time to recovery of the train-of-four ratio to 0.9 (TOFR\(_{=0.9}\)) were recorded. The differences between monitored sites were compared using one-way ANOVA followed by a post hoc Dunn’s test.

Results. Onset of ROC was significantly delayed in OOM compared with both limbs [pelvic limb, thoracic limb, and OOM: 43.1 (SD 16.9), 50.6 (15.9), and 204.4 (35.8) s, respectively; \(P<0.001\)]. Complete block was achieved in the pelvic and thoracic limbs, but in none of the eight ponies in the OOM [mean T1 = 15.3 (9.4)%; range: 7–36%]. No differences were observed between muscle sites in recovery to TOFR\(_{=0.9}\) [pelvic limb, thoracic limb, and OOM: 2.3 (0.9), 3.4 (1.7), and 2.8 (2.1) min, respectively]. No adverse effects of sugammadex were detected throughout the study period.

Conclusions. Sugammadex can be used to reverse profound rocuronium-induced block in ponies during isoflurane anaesthesia. Thoracic limb muscles represent a suitable alternative for monitoring neuromuscular block compared with pelvic limb muscles.

Keywords: neuromuscular block; neuromuscular monitoring; pony; sugammadex; veterinary anaesthesia

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Neuromuscular blocking drugs are not widely used in equine anaesthesia due to financial considerations, increased monitoring requirements, and the possibility of residual block during recovery. Residual block in equine patients is a significant factor in a poor recovery from general anaesthesia, which is linked with a high perioperative mortality rate (0.9% in healthy horses).\(^1\) 2 If effective, sugammadex would provide a novel approach to the use of neuromuscular blocking agents in equine anaesthesia.

To date, only two monitoring sites have been identified as useful in horses, the peroneal nerve stimulating the digital extensor muscles of the pelvic limb and the buccal branches of the facial nerve supplying the levator nasolabialis muscle.\(^1\) 3–6 Several studies have identified significant differences in the sensitivity of the two muscle groups to neuromuscular blocking drugs with the head muscles being more resistant than the limb muscles.\(^4\) 5 7

This study aimed to evaluate the effect of sugammadex on profound rocuronium-induced block in ponies and to monitor neuromuscular block at three muscle sites using acceleromyography. A new monitoring site on the thoracic limb not reported previously was compared with the two traditional sites. The stimulation sites were identified using percutaneous electrical nerve stimulation. Preliminary results presented in this paper have been published in abstract form.\(^8\)

Methods

Animals

The study protocol was approved by the Institutional Ethics Committee of the Veterinary University Vienna and had governmental approval (GZ68.205/0150-II/10b/2008). Eight healthy adult Shetland pony geldings with a mean age of...
7.2 (3.5) yr and a body weight of 117 (23.4) kg were included. Ponies were housed overnight before the experiment, and food was withheld for 12 h but free access to water was allowed. On the basis of physical examination and standard blood analysis, all ponies were deemed to be ASA I status.

**Anaesthesia**

Anaesthesia was induced with isoflurane in oxygen 100% via a face mask. Once the pony was anaesthetized, tracheal intubation was performed with a cuffed tracheal tube (ID 57 Fr). Ponies were placed in right lateral recumbency on the operating table and anaesthesia was maintained with isoflurane (end-tidal concentration 1.5%) in oxygen 100%. Volume controlled intermittent positive pressure ventilation was initiated (Servo 3000, Siemens, Vienna, Austria) and end-tidal carbon dioxide tension ($\text{P}_{\text{ETCO}_2}$) maintained between 4.66 and 5.99 kPa.

The right jugular vein was catheterized to permit fluid and drug administration. Intravenous sodium chloride 0.9% (Fresenius Kabi AG, Bad Homburg, Germany) was administered throughout the procedure at 6 ml kg$^{-1}$ h$^{-1}$. The left transverse facial artery was catheterized to permit invasive arterial pressure measurement and blood sample collection. If mean arterial pressure decreased below 60 mm Hg, dobutamine (Nycomed, Vienna, Austria) was infused at 1 $\mu$g kg$^{-1}$ min$^{-1}$ i.v. Heart rate (HR), systolic arterial pressure (SAP), diastolic arterial pressure (DAP), and mean arterial pressure (MAP), pharyngeal temperature ($T$), the ECG, end-tidal isoflurane concentration ($\text{P}_{\text{ETISO}}$), $\text{P}_{\text{ETCO}_2}$, expiratory tidal volume (VT), respiratory rate ($f$), and peak airway pressure ($P_{\text{peak}}$) were continuously monitored and recorded every minute using multiparameter monitors (Datex-Ohmeda S/5 GE, Healthcare, Finland, and NICO 2, Novametrix Medical Systems Inc., Wallingford, CT, USA).

**Neuromuscular monitoring**

The following nerve–muscle units were monitored: (i) the digital extensor muscles of the pelvic limb by direct stimulation of the superficial peroneal nerve, (ii) the carpal and digital extensor muscles of the thoracic limb by direct radial nerve stimulation, and (iii) the orbicularis oris muscle (OOM) by direct stimulation of the ventral buccal branch of the facial nerve. The peroneal nerve was identified on the non-dependent side of the head in a groove caudal to the orbicularis oris and ventral to the zygomatic muscle, caudoventral to the commissure of the lips.

The optimal positions for the stimulating electrode of the acceleromyograph at all three sites were located using percutaneous electrical guidance (PEG). The anode lead of the nerve locator (Pajunk, Geisingen, Germany) was connected to a needle penetrating the skin close to the anticipated stimulation site. The area was clipped and contact gel applied. The PEG probe was firmly applied to the skin and stimulation (10 mA; 2 Hz) initiated. The probe was slowly moved until maximum extension of the hoof or maximum movement of the lower lip was observed. The current was then gradually reduced until maximum movement at the lowest amperage was determined. This current was recorded. For neuromuscular monitoring, a needle with a metal luer lock hub was inserted s.c. at the point identified by the PEG probe and connected to the stimulation (negative) electrode of the nerve stimulator. Another needle was inserted ~3 cm proximally, to which the zero (positive) electrode was connected.

Neuromuscular monitoring was performed using acceleromyography (TOF-Guard, Organon, Boxtel, The Netherlands). Acceleration transducers were fixed on the most distal part of the dorsal hoof wall with tape, or with cyanoacrylate adhesive to the lower lip of the ponies at the site of maximal movement. A train-of-four (TOF) stimulation pattern (2 Hz, 2 s duration, every 15 s) was used with a supramaximal stimulus (40 mA).

Nerve stimulation was continued for 20 min before administration of rocuronium in order to allow stabilization of the recordings and regulation of the depth of anaesthesia; isoflurane delivery was adjusted to maintain a minimum end-tidal concentration consistent with stable anaesthesia during electrical stimulation (~1.5 × MAC). All nerve stimulators were calibrated to a height of 100% for the first twitch of the TOF according to the manufacturer’s guidelines 15 min before rocuronium administration.

**Administration of rocuronium and sugammadex**

Rocuronium 0.6 mg kg$^{-1}$ was administered over 30 s. A baseline TOF was recorded at the start of injection. Five minutes after the end of the rocuronium injection, sugammadex 4 mg kg$^{-1}$ was injected over 30 s. Arterial blood gas analysis was performed at 5 min before and 10, 30, and 60 min after rocuronium administration (AVL Compact 3, Roche Diagnostics GmbH, Mannheim, Germany). Sixty minutes after rocuronium administration, the ponies were decatheterized, the monitoring devices were removed, and isoflurane administration was stopped. The ponies were then moved to a padded recovery box and continuously monitored until they had regained the standing position.

Latag time (lagROC=time in seconds from the start of injection until first depression of the TOF response) and onset time of ROC (onsetROC=time in seconds from the start of injection until maximum block), maximum block (%), lag time from the beginning of sugammadex injection to first observed response (lagSUG in seconds), recovery of T1/T0 to 25% and 75% (in seconds), recovery index (T1/T0 25–75% in minutes), and time to recovery of the TOF ratio to 0.9 (TOFR=0.9 in minutes) were recorded. The original height of T1 was taken as the baseline value.
Statistical analysis
Pharmacodynamic data for rocuronium and sugammadex and minimal PEG currents for the three stimulated nerve–
muscle units were compared using one-way ANOVA followed by post hoc Dunn's test. Changes in HR, SAP, DAP, MAP, T, \(P_{\text{Es}}\), \(P_{\text{EsCO2}}\), VT, \(R_{\text{f}}\), and \(P_{\text{peak}}\) were analysed within subjects from 5 min before rocuronium injection (baseline value) until 10 min after sugammadex injection using a paired Student’s t-test.

Statistical analysis was performed using NCSS statistical software, Version 2004 (NCSS2004/PASS2002, Kaysville, Utah, USA). Data are reported as mean (SD) and range (minimum–maximum) for the neuromuscular variables and blood gas values. Differences were considered statistically significant at \(P<0.05\).

Results
No significant effects on physiological variables were observed after rocuronium or sugammadex administration (Table 1). Mean (\(\pm\)range) end-tidal isoflurane concentrations were 1.6 (0.3) (1.5–2.1)%. No adverse effects were detected in the blood gas values from 5 min before to 60 min after rocuronium. The mean (\(\pm\)) arterial oxygen partial pressure remained between 58.4 (15.0) kPa 5 min before rocuronium and 54.9 (17.2) kPa 60 min after rocuronium with a range of 13.3–69.0 kPa. The mean (\(\pm\)) arterial carbon dioxide partial pressure was 5.8 (0.6) kPa before rocuronium and 5.9 (0.8) kPa after rocuronium with a range of 4.5–6.9 kPa. There was a non-significant decrease in the arterial pH during anaesthesia (pH 5 min before rocuronium: 7.35 (0.04); pH 60 min after rocuronium: 7.33 (0.05); range: 7.26–7.41).

The mean (\(\pm\)) current needed to provoke visible movement with the PEG probe for the peroneal, radial, and facial nerves was 1.9 (0.9), 3.1 (0.5), and 2.3 (0.7) mA, respectively. A significantly higher current was needed for the radial nerve to provoke movement compared with the peroneal and facial nerves (\(P<0.001\)).

Pharmacodynamic data for rocuronium and sugammadex
Table 2 presents the neuromuscular variables from the start of administration of rocuronium to the recovery to the predefined indices. Figure 1 shows typical TOF graphs recorded in one pony in the three muscle groups.

Mean (\(\pm\)) lag time for rocuronium was 43 (9.6), 41 (10.6), and 41 (10.6) s and onsetROC 73 (16.9), 81 (15.9), and

### Table 1

<table>
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<th>Time/values</th>
<th>HR (beats min(^{-1}))</th>
<th>SAP (mm Hg)</th>
<th>DAP (mm Hg)</th>
<th>MAP (mm Hg)</th>
<th>(T) (°C)</th>
<th>(P_{\text{Es}}) (vol%)</th>
<th>(P_{\text{EsCO2}}) (kPa)</th>
<th>VT (ml)</th>
<th>(P_{\text{peak}}) (cm H(_2)O)</th>
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193 (38.8) s for the pelvic limb, thoracic limb muscles, and head muscles, respectively (Fig. 2). No TOF response was detectable in any pony in either limb muscle at the start of administration of sugammadex. Partial block was present in the OOM at this time point with a mean T1/T0 of 15.3% (9.4) (range 7–36).

Mean (so) lag time for sugammadex in the extensor muscles of the pelvic limb was 52 (13.9) and 71 (26.0) s in the thoracic limb muscles. In the OOM, lagSUG was 23 (11.3) s.

The mean (so) recovery time of T1/T0 to 25% after sugammadex was 90 (24.1) s in the muscles of the pelvic limb and...
129 (50.7) s in the thoracic limb muscles (Fig. 2). T1/T0 reached 25% in <1 min in the OOM [51 (21.0) s]. The mean recovery index (T1/T0 25–75%) (so) in the pelvic limb, the thoracic limb, and the OOM was 3.5 (2.0), 1.2 (3.4) and 2.9 (1.3) min, respectively.

A mean (so) TOFR of 0.9 was achieved at all three monitoring sites in <4 min: in the pelvic limb, thoracic limb, and OOM after 2.3 (0.9), 3.4 (1.7), and 2.8 (2.1) min, respectively.

There was no evidence of recurarization in any pony during the 55 min period of general anaesthesia after sugammadex administration.

Comparison of stimulation sites

Figure 2 shows the T1/T0 trends between the three stimulation sites from the beginning of rocuronium administration to maximum block and from administration of sugammadex until T1/T0 reached 100%.

No significant difference was seen in lagROC between the stimulation sites. However, onsetROC was significantly delayed and not complete in the OOM compared with the muscle groups of both limbs (P<0.001, Fig. 2).

The time to detection of T1 (lagSUG) and T1/T0=25% after administration of sugammadex was significantly faster in the OOM compared with both extensor muscle groups (P<0.001 for lagSUG and P<0.002 for T1/T0=25%). The mean time to reach T1/T0=25% was the only index showing a significant difference between the two limb stimulation sites, with the pelvic limb muscles showing a shorter recovery time than the thoracic limb muscles (P<0.002, Fig. 2).

The time T1/T0=75% and the recovery index T1 25–75% were similar in all three stimulation sites (P<0.124 and P<0.7, respectively). No significant differences were found between the three stimulation sites in the recovery of TOFR=0.9 (P<0.442).

Discussion

This is the first study describing the effect of sugammadex in the equine species. Furthermore, a new stimulation site on the thoracic limb was compared with the routinely used stimulation sites on the pelvic limb and head. The optimal location for the stimulating electrode at each site was determined using PEG, thus ensuring the best possible comparison between muscle sites and ponies.

Pharmacodynamics of rocuronium and sugammadex

Rapid and complete reversal of neuromuscular block is essential in horses as the high anaesthesia-associated mortality rate is correlated with the duration of anaesthesia.2 9 Our study demonstrates that sugammadex 4 mg kg⁻¹ can reverse profound rocuronium-induced block within 4 min. In comparison, spontaneous recovery of the TOFR to 0.9 after rocuronium 0.6 mg kg⁻¹ in horses takes 65.4 (10.8) (49.0–83.5) min.10 The time to recovery of T1/T0 to 25% (the time point at which acetylcholinesterase inhibitors can be administered to effectively reverse neuromuscular block after rocuronium) is only reached after 55.0 (9.8) (40.5–72.2) min.10 In ponies, high doses of neostigmine (0.04 mg kg⁻¹) and edrophonium (1 mg kg⁻¹) can reverse neuromuscular block within 10 min when T1/T0 has reached 10%.11 However, serious side-effects such as hypertension, bradycardia, severe salivation, and gastrointestinal signs were observed with this technique.11

The lowest reported dose of sugammadex for safe reversal of profound rocuronium block in humans was chosen, as economic concerns are likely to be paramount in determining whether this protocol is utilized in veterinary clinical practice.12–15 The recovery time to TOFR=0.9 was the same in the pelvic limb muscles in ponies [2.3
(0.9) min] as the upper limb muscles in humans when the same doses of rocuronium and sugammadex with the same time interval between administrations were used [2.3 (0.7) min].

Neither rocuronium nor sugammadex caused significant alterations in any cardiovascular variables in the eight ponies. Hypotension is a common problem in anaesthetized horses. Dobutamine is the preferred drug to increase arterial pressure in normovolaemic animals due to its high β-adrenoceptor selectivity. The use of dobutamine in two ponies in this study is not unusual and was not related to administration of any of the study drugs as both ponies required it before rocuronium administration.

In humans, signs of insufficient depth of anaesthesia such as grimacing, moving, coughing, bucking, and sucking on the tracheal tube were reported in up to 22% of patients receiving sugammadex. No signs of insufficient depth of anaesthesia were observed after administration of sugammadex in our ponies as no increase in delivery of isoflurane was required during the study period (Table 1). This is encouraging, as any degree of movement may have serious safety implications for both horse and attending personnel. End-tidal concentrations of isoflurane needed to maintain stable anaesthesia during supramaximal electrical stimulation at three sites were close to the 1.5 × MAC value which is 1.3% in horses.

**Neuromuscular monitoring**

The temperament of horses predisposes them to incurring injuries during recovery from anaesthesia, with limb fractures accounting for 25% of all perioperative fatalities. Good limb co-ordination and muscular strength are crucial in avoiding a potentially catastrophic incident when the animal attempts to rise. For this reason, a pelvic limb nerve–muscle unit is routinely used for monitoring neuromuscular block. Manley and colleagues stimulated the ulnar nerve in ponies and monitored flexion of the thoracic limb, but their approach proved unsuitable for quantitative and qualitative evaluation of neuromuscular block in this species. In contrast, we were able to stimulate the radial nerve distal to the elbow joint to provoke a reproducible extension of the limb distal to the carpus. We found no difference in TOF variables over time between the thoracic and pelvic limbs. This provides the veterinary anaesthetist with an alternative but comparable stimulation site to the pelvic limb when the latter is not accessible during such surgical procedures as laparotomy. The landmarks on the thoracic limb, however, are obscure and the best location for stimulation is not easy to find without using PEG.

Different branches of the facial nerve have been used to provoke movement of the upper lip giving qualitatively stable results. However, previous studies have shown that the head muscles are more resistant to non-depolarizing neuromuscular blocking agents in ponies than the more important limb muscles. We were able to confirm these findings, proving the head to be an inadequate stimulation site. Even if no statistically significant difference was seen in the TOFR = 0.9 between the three monitoring sites, a variation in was seen between the three muscle groups with the pelvic limb muscles having the lowest (0.9 min) and the OOM having the highest (2.1 min) variability. This emphasizes that the results obtained from monitoring the facial muscles are the least reliable during rapid reversal with sugammadex.

Sensitivity of various muscle groups to neuromuscular blocking agents is poorly understood. The size and the composition of the fibres and the density and location of acetylcholine receptors may have an influence. However, the reason why the head muscles in horses are more resistant to neuromuscular blocking agents compared with the limb muscles is obscure. The shorter lagSUG and recovery to T1/T0 = 25% in the OOM compared with the limb muscles is not surprising as only a partial block was evident at the time of reversal. Variable circulation times to individual muscles and variable muscle blood flow may contribute to differences in the lag times and the time to reach T1/T0 = 25% between the different muscle groups.

PEG proved to be a very useful tool in identifying the best stimulation site. Previously described landmarks for locating the common peroneal nerve just distal to the head of the fibula proved unreliable, requiring a high amperage and producing inconsistent responses. Accurate location of the superficial peroneal nerve using PEG allowed placement of the stimulating electrode directly over it resulting in qualitatively and quantitatively consistent responses. The deep branch of the radial nerve is located below muscle fascia and the ulnaris lateralis muscle. The higher amperage needed to stimulate this nerve compared with the other two nerves used in this study reflects this deeper pathway. The radial nerve branch used in this study runs perpendicular to the groove between the bellies of the lateral digital extensor and the ulnaris lateralis muscles giving a very narrow accessible window. This may make optimal positioning of the stimulating electrode difficult in a clinical setting without having PEG available. Further clinical studies are needed in this respect.

The major limitation of the study is the small number of subjects. Incorporating PEG facilitated standardization of neuromuscular monitoring and improved reproducibility. Future studies are needed to evaluate the cost benefits of a rapid reversal compared with the risk of prolonging anaesthesia time in equine patients in a clinical setting.

We conclude that sugammadex 4 mg kg⁻¹ can be used to reverse profound rocuronium-induced block in ponies within 4 min. This is an important finding in a species where the duration of anaesthesia is directly correlated with mortality and makes sugammadex a promising drug for use in horses. Monitoring the thoracic limb muscles by stimulating the radial nerve results in TOF indices comparable with those detected in the traditional nerve–muscle unit used in the pelvic limb.
Conflict of interest

J.M.H. undertook Phase III clinical trials of sugammadex funded in part by Organon Technika 4 yr ago. J.M.H. is Chairman of the Editorial Board of the BJA and a Director of BJA Ltd.

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References