VETERINARY ANAESTHESIA AND ANALGESIA

Proximal RUMM block in dogs: cadaveric and clinical study

Journal:	*Veterinary Anaesthesia and Analgesia*
Manuscript ID	VAA-18-0040
Article Type:	Research Study
Keywords:	ultrasound, loco-regional anaesthesia, proximal RUMM block, axillary sheath, Dog

Word count introduction to discussion: 3528

Abstract

Objective To evaluate intra and postoperative efficacy of an ultrasound (US)-guided radial (R), ulnar (U), median (M) and musculocutaneous (Mc) nerve blocks, performed together in the axillary space by a single in-plane approach.

Study design Anatomical research and prospective clinical study.

Animals Three dog cadavers and 15 client-owned dogs undergoing thoracic orthopaedic limb surgery.

Methods

In Phase-1, anatomical dissection and US study of the axillary space were performed to design an US-guided proximal RUMM block.

The technique was considered successful if 0.15 mL kg^{-1} of new methylene blue solution completely stained for ≥ 2 cm the four nerves in two cadavers.

In Phase-2, the US-guided proximal RUMM block designed on phase 1 was performed as analgesic strategy in fifteen client-owned dogs undergoing orthopaedic thoracic limb surgery using a total volume of 0.15 mL kg^{-1} of ropivacaine 0.5%. Intraoperative success rate (fentanyl requirement < 1.2 mcg kg^{-1} $hour^{-1}$) and analgesic duration of the block, by a postoperative pain score (Short form Glasgow composite measure pain scale, SF-GCMPS ≥ 5/20) were evaluated.

Results

In Phase-1, R, U, M, and Mc nerves detection resulted always feasible by a single US-window at axillary space. Axillary artery and the Mc nerve were used as landmarks. In-plane needling approach was feasible in 2/2 cases with all the nerves completely stained for >2 cm. No intrathoracic dye spread was found.

In Phase2, the proximal RUMM block prevented cardiovascular response in 14 out of 15 anaesthetised dogs. Mean analgesic duration of the block resulted 8 hours.

Conclusion and clinical relevance

The US-guided proximal RUMM block performed at the axillary level with a single in-plane needling approach using 0.15 mL kg^{-1} of ropivacaine 0.5%, minimized the use of fentanyl during thoracic limb surgery and postponed the rescue analgesia up to 8 hours from the peripheral nerve block execution.

Keywords: Ultrasound, loco-regional anaesthesia, proximal RUMM block, axillary sheath, dog.

Introduction

Thoracic limb surgery is performed in small animals for a variety of procedures (Trumpatori et al. 2010); its innervation arises from the brachial plexus (BP) which branches into four main nerves: radial nerve (R), ulnar nerve (U), median nerve (M), and musculocutaneous nerve (Mc) (Evans & de Lahunta 2012b).

Individual R, U, M, and Mc nerves block, can be performed distally to the BP to provide forelimb sensory and motor block without shoulder impairment (Curatolo et al. 2005).

In veterinary anaesthesia, RUMM block has been traditionally approached at the mid-humerus level through anatomical landmarks (Trumpatori et al. 2010) or using a nerve-stimulated technique (Bortolami et al. 2012). With both techniques, the R nerve is approached from the lateral aspect of the limb, while the other nerves from the medial aspect, changing animal recumbency and requiring multiple needling (Trumpatori et al. 2010).

Introduction of ultrasound (US) guided-PNB techniques increased loco-regional anaesthesia efficacy and reproducibility (Marhofer & Fritsch 2017). Although to date, there is no study comparing nerve-stimulated *vs* US-guided techniques for RUMM block in dogs, the last (Portela et al. 2013; Castiñeiras et al. 2015) showed promising results.

In human medicine, some limitations regarding US-guided RUMM block at the mid-humerus level already emerged: premature bifurcation of the cutaneous nerve branches may lead to ineffective or patchy blocks, and the multiple injections needed may increase execution time and the risk of nerve injury (Sehmbi et al. 2015).

Consequently, in human medicine the US-guided axillary block became the most widely used approach for the thoracic limb nerves, and the reason for its success lies in the anatomical area. At this level, a connective sheath, derived from the deep cervical fasciae, surrounds the neurovascular bundle bringing the nerves close to each other (Thompson & Rorie 1983; Ay et al. 2007; Alemanno et al. 2014). Furthermore, in the majority of patients, RUMM nerves run superficially making the area suitable for a US scanning (Nowakowski & Bierylo 2015).

In veterinary medicine there are discordant opinions regarding the axillary sheath (AS): for some authors, it does not exist in dogs, and the axillary approach gives weaker results than in humans (Wenger et al. 2005) while Evans & de Lahunta (2012a) confirm the presence of an AS in dogs; this area was also studied for endoscopic access to the axillary lymph nodes (Prieto et al. 2007).

The axillary region has been previously investigated in dogs through US anatomical studies (Guilherme & Benigni, 2008; Campoy et al. 2010) with the aim to approach the BP but not specifically the RUMM nerves. No reference to the presence of an AS is mentioned in neither of these studies.

The hypothesis of the present study is that the deep axillary fasciae continues to form a sheath around the neurovascular structures at the level of the axillary space in dogs and it could be responsible for incomplete blocks when the local anaesthetic (LA) is injected outside. The use of US could be crucial to verify the right positioning of the LA inside the sheath resulting in a more successful and predictable RUMM block.

Therefore, the aims of the present study were: 1) to find a sole US window at the axillary space where the RUMM nerves can be simultaneously visualized on their short axis surrounded by the AS; 2) to design an in-plane approach involving all the nerves with one needling technique and 3) to evaluate the intraoperative success rate of the proximal RUMM block and its post-operative duration in dogs undergoing thoracic limb surgeries.

Materials and methods

The study was conducted in compliance with the European Welfare Act and with the approval of the local Ethical Committee (N. 4627). Written owner's consent was obtained for the collection and use of data for all dogs included in this study.

The study was divided into two phases: phase-1, which included anatomical dissection and US scan of the axillary space to design the block and the needling technique, and phase-2, which included clinical application of the designed block in phase-1.

Phase-1 anatomical and sono-anatomical study.

Three dogs, euthanized for reasons unrelated to the study were enrolled. The study was carried out within a period of 6 hours after euthanasia. One Labrador (weight 37.5 kg; BCS 5/9) was dissected for the gross anatomy study, for each side, in order to define the relationship between nerves and associated structures. Laying the animal in dorsal recumbency, the skin and the relative superficial fasciae of the ventral aspect of the neck and from the elbow to the sternum were reflected. Then, the overlying fascia was removed to expose the muscles. Superficial and transverse *pectoralis* and part of deep *pectoralis* muscle were transected and *cleidobrachialis* muscle removed exposing the axillary space.

In two other cadavers, a Pointer (weight 18.5 kg; BCS 4/9) and a crossbreed (weight 27.3 kg; BCS 4/9), an US scan of the booth axillary spaces has been performed.

Ultrasound probe placement and block technique

With the dog in dorsal recumbency, the thoracic limb was abduced by 90°, and rotated externally. A high-frequency 12 MHz linear probe (Venue 40; **) was positioned on the medial aspect of the arm, at the level of the humeral head, transverse to the longitudinal axis of the humerus, with its mark facing cranially (Fig. 1). After identification of the boundaries of the AS, represented by the *biceps brachii* and the *coracobrachialis* muscles cranially, the *pectoralis* muscles medially and the lateral head of the *triceps brachii* muscle laterally, the probe was tilted to visualize the RUMM nerves, the brachial vessels and the AS. Using an in-plane technique, a 22 G, 30° bevel, 85 mm needle (Visioplex; Vygon, **) was advanced caudally, through the belly of the *biceps brachii* muscle towards the Mc, R, and M-U nerves, cranial and caudal to the brachial artery, respectively (Fig. 1).

A total volume 0.15 mL kg^{-1} of new methylene blue (NMB) solution, divided into three aliquots was injected as following: first the Mc nerve was injected with 0.03 mL kg^{-1}; secondly, the R nerve with 0.07 mL kg^{-1}, and finally, because the U-M nerves lay together, a unique injection of 0.05 mL kg^{-1} was performed. Subsequently, the axillary space was dissected and the distribution of the stain evaluated. A complete staining of ≥ 2 cm per nerve was considered successful. The presence of dye on the target nerves and the lack of it on the associated tissues beyond the limits of the AS were considered as evidence of this sheath acting as a barrier to the injected solution.

Phase-2: clinical study

Phase-2 included fifteen dogs undergoing forelimb orthopaedic surgery (distally to the mid-humerus), performed at ** University Veterinary Teaching Hospital.

With an α error of 0.05, and a β error of 0.2, considering a mean fentanyl infusion of 1.2 mcg $kg^{-1}hour^{-1}$ as the maximum end-point, the number of dogs required was 9. The maximum end-point infusion of fentanyl was decided on the basis of the data reported by a previous study, (Wenger et al. 2005), in which a successful PNB received a median infusion rate of fentanyl of 0 mcg kg^{-1} hour^{-1} with a range between 0-1.2 mcg kg^{-1} hour^{-1}. The null hypothesis was considered if the dog received more than 3 mcg kg^{-1} hour^{-1} (Wenger et al. 2005).

Based on physical examination, haematology and biochemistry analyses only dogs classified as the American Society of Anaesthesiologist's classification system physical status I-III and with a BCS (Freeman et al. 2011) ranging between 3 and 6 out of 9 were included in the study. Exclusion criteria consisted in skin infections, intractable behaviour, neurological or neuromuscular disease and owner's refusal. Food but not water was withheld 8 hours prior to surgery. All dogs were premedicated intramuscularly with acepromazine (0.01 mg kg^{-1}) (**) and methadone (0.1 mg kg^{-1}) (**). After 20 minutes, a 20G catheter was aseptically placed in the lateral saphenous vein and lactated Ringer's solution at 5 mL kg^{-1} hour^{-1}, was started. Approximately 20 minutes later, anaesthesia was induced with propofol (**) intravenously (IV) titratd to effect. After tracheal intubation, all dogs were connected to a re-breathing system and anaesthesia was maintained with isoflurane (**) in a mixture of medical air and oxygen (FiO_2 0.6-0.7). A catheter (22 or 20 gauge) was placed in the dorsal pedal artery to measure invasive arterial blood pressure (IBP).

The skin of the axillary space was aseptically prepared and US-guided proximal RUMM block was performed as described in phase-1, using a total volume of 0.15 mL kg^{-1} of ropivacaine 0.5% (**). Before injecting the LA, the distance (cm) from the transducer to the dorsal wall of the brachial artery was recorded from the US images on the screen. The time required to perform the RUMM block, defined as the period from brachial artery identification to the injection being completed, was recorded (Akasaka &

Shimizu 2017). During anaesthesia, heart rate (HR), respiratory rate, IBP, end-tidal carbon dioxide ($PE'CO_2$), end-tidal isoflurane (FE´Iso) and peripheral oxygen saturation were continuously monitored and recorded every five minutes and at defined surgical time points (Table 1) using a multiparameter monitor (S5 Compact Anaesthesia Monitor; Datex Ohmeda, **). For the IBP a transducer positioned and zeroed at the level of sternum, was used.

The recorded five minutes before the start of the surgery was reported as T_0 and considered as baseline. The initial (T_0) F_E'Iso was set to 1.2 % and decreased by 0.05 % every five minutes, if the recorded physiological parameters remained within 20% of baseline (Mosing et al. 2010). In case HR or MAP_{inv} increased 20% or more compared to T_0 values (Wenger et al. 2005), intraoperative fentanyl (**) was administered as follow: up to two boluses of 1 mcg kg^{-1} IV and in case of unrestored parameters, an infusion started at 0.5 mcg kg^{-1} $hour^{-1}$ titrated to effect. The PNB was considered successful if the total amount of fentanyl administered was < 1.2 mcg kg^{-1} $hour^{-1}$ (Wenger et al. 2005).

Animals were mechanically ventilated (Datex-Ohmeda 7900 SmartVent, GE Healthcare, **) to maintain $PE'CO_2 \leq 45$ mmHg. The same investigator, different from the one who executed the block, followed all the intraoperative anaesthetic period and recorded all the parameters. The same surgeon performed all the surgeries. After extubation, 2 mg kg^{-1} carprofen (**) was administered SC. Pain was assessed before premedication (Preop), and postoperatively every hour starting from 1 hour after spontaneous head lifting (T1) using the Short-Form Glasgow Composite Measure Pain Scale (SF-GCMPS) (Reid et al. 2007) by an investigator, different from the previous, trained in the use of the scale and unaware of the analgesic protocol. Postoperative rescue analgesia (methadone 0.2 mg kg^{-1} IV) was provided with SF-GCMPS ≥5. Elapsed time from the PNB execution to first rescue analgesia treatment was recorded as postoperative analgesic duration of the block. A month follow-up period was planned to evaluate any neurological deficits or side effects, such as skin reaction, pruritus and pain of the injection site.

Statistical analysis

Data were analysed for normal distribution with the D'Agostino & Pearson test using statistical software (Prism 6-2; GraphPad Prism Inc., CA, USA). Data were expressed as mean ± standard deviation. A one-way ANOVA test for repeated measures with a Bonferroni test as post hoc was used to assess differences for each clinical parameter in relation to time. Values of $p<0.05$ were considered significant.

Result

Phase-1

Anatomical study

The gross anatomical study revealed the presence of the AS (a thick layer of axillary/brachial fasciae) completely surrounding and containing the nerves and the vessels (Fig. 2).

Starting from cranial to caudal, the Mc nerve was located cranially to the brachial artery; at the humeral head level it splits into two branches: one running cranial towards the biceps brachii muscle and the second one distal to the elbow region. The R nerve lied deeper and laterally to the brachial artery at the proximal third of the humerus to then pierces the AS towards the lateral aspect of the arm. The M and U nerves run in close contact to each other caudal to the brachial artery and cranial to the brachial vein (Fig. 2).

Ultrasound study

The interested structures were located superficially, 1 to 3 cm beneath the skin. The brachial artery was identified as a circle anechoic structure and the brachial vein as an oval and compressible anechoic structure. The nerves, visualized transversally, appeared as hypoechoic round structures surrounded by a hyperechoic circular bundle, the epineurium. The complete US scan of the axillary region has been crucial to determine the most convenient site to perform the block, and to precisely define where the R nerve was still inside the AS and the proximal muscular branch to the biceps brachii muscle of the Mc nerve had not arisen yet.

With the brachial artery centred in the US screen, a gentle tilting movement of the probe allowed to identify the four nerves in a sole US window in 2 out of 2 cases (Fig. 3). The real time needle's advancement into the AS and the distribution of the NMB around the nerves was possible in all injections. The dissections showed a circumferential dye spread of >2 cm along all the RUMM nerves. Due to the presence of the AS, no stain was found in the tissues outside the mentioned sheath (Fig. 4). No dye inside the thoracic cavity or around the phrenic nerve was detected.

Phase-2 clinical trials

All fifteen dogs enrolled completed the study uneventfully. Animals were aged 42.9 ± 28 months old and weighed 19.9 ± 7.9 kg. Dogs' breed and weight distribution are reported in Table 2.

Median preoperative pain score was 3 (1-4); mean propofol dosage for the induction resulted 3.04 ± 0.57 mg kg^{-1}. Time to perform the proximal RUMM block was 9 ± 2.9 minutes; time elapsed between the PNB execution and the beginning of the surgery was 43 ± 7.2 minutes, surgery time (T_1-T_5) was 227 ± 42.1 minutes, and the time between the PNB execution and the end of surgery was 270 ± 44.7 minutes.

Regarding F_E'Iso values, no statistical differences were detected between the surgical time points monitored with a mean value of F_E'Iso ≈ 1.00%, lower than minimum alveolar concentration of isoflurane reported in literature for dog (Steffey et al. 2015).

The distance between the transducer and the dorsal aspect of the artery was 1.56±0.48 cm.

In one dog (animal 1) starting from time T_2, 2 boluses of fentanyl followed by fentanyl infusion > 3 mcg kg^{-1} hour^{-1} for the entire procedure were administered to restore an adequate analgesic level and the PNB was considered unsuccessful. For the remaining 14 dogs, a total of three episodes of fentanyl bolus administration at 1 mcg kg^{-1}, were recorded (animals 8, 12 and 15 at time T_5, T_1 and T_5, respectively) with a mean infusion rate of 0.25 mcg kg^{-1} hour^{-1}. However, no dogs required intraoperative fentanyl infusion above the determined maximum end-point and therefore the blocks were considered successful in 14 out of 15 cases.

At the end of the surgery, animal 1 received methadone (0.2 mg kg^{-1} IV) due to the lack of PNB's and was excluded from the postoperative evaluation.

In the remaining dogs (*n*=14), the time elapsed to the first rescue analgesia administration was 501 ± 35 minutes from PNB execution and 231± 60 minutes from spontaneous head lifting. No neurological complications or cutaneous alterations at the injection site were observed during the 30 days follow-up period.

Discussion

This is the first study showing the presence of an AS surrounding all the nerves involved in the innervation of the thoracic limb in dogs. The injection of dye inside the AS was exclusively confined to the target nerves without involving the surrounding tissues, thus representing a unique benefit in the execution of the RUMM block through a proximal approach.

In addition, the results gained from the present study showed that US-guided proximal RUMM block using 0.15 mL kg^{-1} of ropivacaine 0.5%, reduced the intraoperative nociception and limited the requirement of systemic opioids in dogs undergoing forelimb surgery. The first postoperative rescue analgesia was administered 8 hours from the PNB execution.

Several complications regarding BP block have been reported: unilateral phrenic nerve block, intravascular injection (Lemke & Creighton, 2008), pneumothorax (Bhalla & Leece, 2015), Horner's syndrome (Viscasillas et al. 2013) and ventricular arrhythmias (Adami & Studer 2015); despite such complications to date the literature on BP blocks outweighs that on RUMM block.

The unpopularity of the RUMM block could be related to the difficulty on execution, the multiple injections needed which are time consuming and increase the risk of vascular and nerve damage (Sehmbi et al. 2015), the low success rate (Trumpatori et al. 2010) and the frequency of patchy anaesthesia recorded (Yamamoto et al. 1999).

The anatomical phase of the present study might explain some of the causes of the low rate of success and the patchy blocks recorded with the nerve-stimulating technique. The presence of the sheath containing the nerves can be responsible of the reduced spread of the LA onto the epineurium when the solution is injected outside the sheath. With the use of a high resolution US device, the visualization of this sheath may turn into an advantage: if the LA is injected inside the sheath, spread of LA around the nerves is warranted.

In the present study, it was possible to localize all the nerves in a single US window in all dogs, with a distance from the transducer to the dorsal wall of the brachial artery ranging from 0.8 to 2.5 cm.

Even if, the time spent to perform the proximal RUMM block was in accordance with the mean time required for US-guided axillary block in humans (8 to 15 minutes) (Imasogie et al. 2010, Tran et al. 2012) it could be reduced with practice as highlighted by the time’s trend to perform the block (table 2).

Regarding the volume and the concentration of LA used for the proximal RUMM block, agreement in terms of volume (0.18 mL kg^{-1} to 0.35 mL kg^{-1}) and concentration (0.25% to 0.75%) was not found in the literature (Trumpatori et al. 2010; Bortolami et al. 2012; Portela et al. 2013; Castiñeiras et al. 2015). The volume employed in the present study was based on the gross anatomical study considering the position and the dimension of the interested nerves. The results gained from phase-1 demonstrated that a volume of 0.15 mL kg^{-1} was sufficient to completely stain all the nerves.

To perform the single approach here proposed, US localization of the Mc nerve above its proximal muscular branch was crucial. The reported difficulty in blocking the Mc nerve is related to the unpredictable relationship that it has with the vascular structure (Spence at al. 2005) and the AS (De Jong 1965; Ay et al. 2007). The anatomical variation of the path of the Mc nerve is responsible for the difficulty in localizing it, (unsuccessful block of animal 1), hindering the choice of the optimal site to perform the PNB (Schafhalter-Zoppoth & Gray, 2005). This event happened in the first dog of the clinical phase but not in the following, highlighting the role of the learning curve.

Intraoperative fentanyl boluses was administered in 3 over 15 animals, only during surgical times involving skin stimulation (T1 and T5); the hypothesis is that some dermatomes, such as the cranial lateral cutaneous brachial nerve and the intercostobrachial nerve (Evans & de Lahunta 2012b) were not covered by the block.

The study has some limitations. As a small number of animals were involved, and because the operator's experience can have a role in the technique success (Barrington et al. 2012), the efficacy of the block should be verified with a higher number of cases in a multicentre study. Methadone was preoperatively administered for ethical purpose, in case of successful block, and this may represent another limitation. The absence of a control group is another drawback. However, a comparison of loco-regional techniques *vs.* systemic administration of analgesics has already demonstrated a higher efficacy and lower stress response in loco-regional treated animals (Romano et al. 2016). It was considered unethical by the authors to include a group with systemic analgesia that has already been shown to produce more side effects.

With the proximal RUMM block here proposed, the authors tried to eliminate three of the main conventional RUMM block inconveniences: all the nerves are approachable without changing the recumbency of the animal, making work on large dogs or dogs with limb fractures easier to handle. Second, with a proximal approach the probability to obtain a patchy block, due to a partial or lack of proximal nerve branches are minimized. Third, the single needling reduces the risk of vascular and nerve damage and the time to execute the block.

The advantages offered by the proximal RUMM block, such as the inexistent risk of damaging the pleura and heart and the minimized possibility to undesirably blocking the phrenic nerve, make this block more worthwhile than a BP block through a paravertebral or an axillary approach.

In conclusion, the US-guided proximal RUMM block performed at the axillary space with 0.15 mL kg^{-1} of ropivacaine 0.5% reduced the intraoperative sympathetic response and limited the requirement of systemic opioids in dogs undergoing forelimb surgery up to 8 hours after the block execution.

References

Adami C & Studer N (2015) A case of severe ventricular arrhythmias occurring as a complication of nerve-stimulator guided brachial plexus location. Vet Anaesth Analg 42, 230-231.

Alemanno F, Bosco M & Barbati A (2014) Chapter 10th Axillary Brachial Plexus Block. In: Anesthesia of the Upper Limb - A State of the Art Guide (1st ed) Alemanno, Bosco & Barbati (eds) Springer-Verlag Italy pp 185-206.

Akasaka M & Shimizu M (2017) Comparison of ultrasound – and electrostimulation-guided nerve blocks of brachial plexus in dogs. Vet Anaesth Analg 44, 625-635.

Ay S, Akinci M, Sayin M et al. (2007) The AS and single-injection axillary block. Clin. Anat. 20, 57–63.

Bhalla RJ & Leece EA (2015) Pneumothorax following nerve stimulator-guided axillary brachial plexus block in a dog. Vet Anaesth Analg 42, 658-659.

Barrington MJ, Wong DM, Slater B et al. (2012) Ultra- sound-guided regional anaesthesia: how much practice do novices require before achieving competency in ultrasound needle visualization using a cadaver model. Reg Anesth Pain Med 37, 334-339.

Bortolami E, Love EJ, Harcourt-Brown TR et al. (2012) Use of mid-humeral block of the radial, ulnar, musculocutaneous and median (RUMM block) nerves for extensor carpi radialis muscle biopsy in a conscious dog with generalized neuro-muscular disease. Vet Anaesth Analg 39, 446-447.

Campoy L, Bezuidenhout AJ, Gleed RD et al. (2010) Ultrasound-guided approach for axillary brachial plexus, femoral nerve, and sciatic nerve block in dog. Vet Anaesth Analg 37, 144-153.

Castiñeiras D, Viscasillas & Seymour C (2015) A modified approach for performing ultrasound-guided radial, ulnar, median and musculocutaneous nerve block in a dog. Vet Anaesth Analg 42, 659-661.

Curatolo M, Felix SP & Nielsen LA (2005) Assessment of regional analgesia in clinical practice and research. Br Med Bull 71,61-76.

De Jong R (1961) Axillary block of the brachial plexus. Anesthesiology 22, 215-225.

Evans HE & de Lahunta A (2012) a Chapter 6th The muscular system In: Miller's Anatomy of the dog (4th ed) Evans HE, de Lahunta A (eds), USA pp 253-254.

Evans HE & de Lahunta A (2012) b Chapter 17th Spinal nerves In: Miller's Anatomy of the dog (4th ed) Evans HE, de Lahunta A (eds), USA pp 611-657.

Freeman LM, Becvarova I, Cave NJ et al. (2011) WSAVA Nutritional assessment guidelines. Journal of Small Animal Practice, 52: 385–396

Guilherme S & Benigni L (2008) Ultrasonographic anatomy of the brachial plexus and major nerves of the canine thoracic limb. Vet Radiol Ultrasound 49, 577-583.

Imasogie N, Ganapathy S, Singh S et al. (2010) A prospective, randomized, double-blind comparison of ultrasound-guided axillary brachial plexus blocks using 2 versus 4 injections. Anesth Analg 110, 1222-1226.

Lemke KA & Creighton CM (2008) Paravertebral blockade of the brachial plexus in dogs. Vet Clin North Am Small Anim Pract 38, 1231-1241.

Marhofer P & Fritsch G (2017) Safe performance of peripheral regional anaesthesia: the significance of ultrasound guidance. Anaesthesia 71,461-469.

Mosing M, Reich H & Moens Y (2010) Clinical evaluation of the anaesthetic sparing effect of brachial plexus block in cats Vet Anaest Analg 37, 154-161.

Nowakowski P & Bierylo A (2015) Ultrasound-guided axillary brachial plexus block Part1-basic sonoanatomy. Anaesthesiol Intensive Ther 47, 409-416.

Prieto PFC, Hernandez MH, Bonet AP et al. (2007) Endoscopic axillary dissection. Experimental model in dogs. Cir Gen 29, 32-36.

Portela DA, Raschi A & Otero PE (2013) Ultrasound guided mid-humeral block of radial, ulnar, median and musculocutaneous (RUMM block) nerves in a dog with traumatic exposed metacarpal luxation. Vet Anaesth Analg 40, 552-554.

Reid J, Nolan A, Hughes J et al. (2007) Development of the short-form Glasgow Composite Measure Pain Scale (CMPS-SF) and derivation of an analgesic intervention score. Anim Welfare 16, 97–104.

Romano M, Portela DA, Breghi G et al. (2016) Stressed-related biomarkers in dogs administered regional anaesthesia or fentanyl for analgesia during stifle surgery. Vet Anaesth Analg 43, 44-45.

Schafhalter-Zoppoth I, Gray AT (2005) The musculocutaneous nerve: ultrasound appearance for peripheral nerve block. Reg Anesth Pain Med 30, 385-390.

Sehmbi H, Madjdpour C, Shah UJ et al. (2015) Ultrasound guided distal peripheral nerve block of upper limb: a technical review. J Anaesthesiol Clic Pharmacol 31, 296-307.

Spence BC, Sites BD, Beach ML (2005) Ultrasound-guided musculocutaneous nerve block: descriptions of a novel technique. Reg Anesth Pain Med. 30, 198-201.

Steffey EP, Mama KR, Brosnan RJ (2015) Inhalation Anesthetics. In: Lumb & Jones Veterinary Anesthesia and Analgesia (5th edn) Grimm KA, Lamont LA, Tranquilli WJ, Greene SA, Robertson SA (eds). Blackwell Publishing, IA, USA, pp. 311 Table 16.7A.

Thompson GE & Rorie DK (1983) Functional anatomy of the brachial plexus sheaths. Anesthesiology 59, 117-122.

Tran DQ, Pham K, Dugani S et al. (2012) A prospective randomized comparison between double, triple, and quadruple injection ultrasound guided axillary brachial plexus block. Reg Anesth Pain Med 37, 248-253.

Trumpatori BJ, Carter JE, Hash J et al. (2010) Evaluation of midhumeral block of the radial, ulnar musculocutaneous and median (RUMM block) nerves for analgesia of the distal aspect of the thoracic limb in dogs. Vet Surg 39, 785-796.

Viscasillas J, Sanchis-Mora S, Hoy C et al. (2013) Transient Horner's syndrome after paravertebral brachial plexus blockade in a dog. Vet Anaesth Analg 40, 104-106.

Yamamoto K, Tsubokawa T, Ohmura S et al. (1999) The effect of arm position on central spread of local anesthetics and on quality of the block with axillary brachial plexus block. Reg Anesth Pain Med 24, 36-42.

Wenger S, Moens Y, Jaggin N et al. (2005) Evaluation of the analgesic effect of lidocaine and bupivacaine used to provide a brachial plexus block for forelimb surgery in 10 dogs. Vet Record 156, 639-642.

Table 1 Surgery time points registered during the procedure

Time	Procedure
T_0	Draping
T_1	Skin incision
T_2	Muscle dissection
T_3	Bone incision/ drilling
T_4	Deep structures suturing
T_5	Skin suturing

Table 2 Breed, weight, distance from the skin to the nerves, time to perform the block and type of surgery of the dogs enrolled in the study.

Patient	Breed	Weight (kg)	Distance (cm)	Time to perform RUMM block (minutes)	Type of surgery
1	Springer Spaniel	23.8	1.2	15	Pancarpal arthrodesis
2	Springer Spaniel	25	1.6	13	Elbow arthrotomy
3	Rottweiler	20	2	13	Proximal ulnar osteotomy
4	German Shepard	30.2	2	12	Proximal ulnar osteotomy
5	Labrador Retriever	35.4	2.5	10	Elbow arthrotomy
6	Springer Spaniel	23	1.6	9	Pancarpal arthrodesis
7	Cross breed	15 5	1.2	7	Distal radio ulnar osteosynthesis
8	Cross breed	9.8	1	8	Metacarpal osteosynthesis
9	Bracco	24	2	7	Distal humerus osteosynthesis
10	Lagotto	13	1.4	7	Radio ulnar osteosynthesis
11	Springer Spaniel	21	1.4	6	Pancarpal arthrodesis
12	Italian Greyhound	6	0.8	8	Distal radio ulnar osteosynthesis
13	Italian Spinone	19.4	1.8	7	Proximal ulnar osteotomy
14	Cross Breed	23.5	2	6	Elbow arthrotomy
15	Cross Breed	10	1	7	Distal radio ulnar osteosynthesis
Mean and St Deviation		***20 ± 8***	***1.5 ± 0.5***	***9 ± 3***	

Figure 1
To perform the ultrasound-guided proximal RUMM block technique, the dog is positioned in dorsal recumbency and the probe is placed at the level of the axillary fossa, caudally to the shoulder joint. The needle is inserted cranio-caudally with an in plane technique.

390x260mm (300 x 300 DPI)

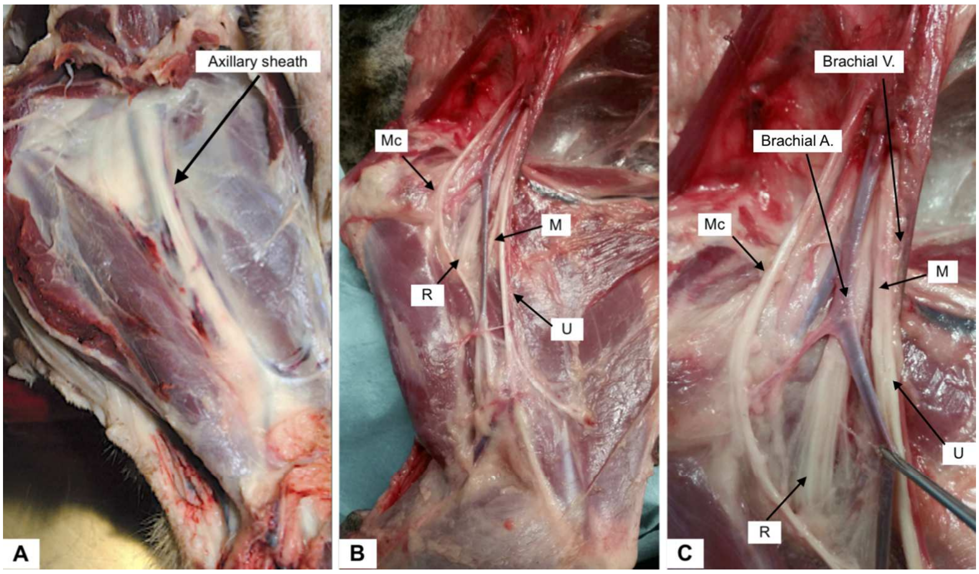

Figure 2
R, U, M, Mc nerves visualization after superficial and deep pectoralis muscles removal. A: axillary sheath containing the nervous vascular bundle. B: R, U, M, Mc nerves exposure after opening the axillary sheath; notice how close the sheath maintained them. R: radial nerve, U: ulnar nerve, M: median nerve, Mc: musculocutaneous nerve. C: enlargement of picture B; it is possible to see the exact point where Mc splits into 2 branches.

129x75mm (300 x 300 DPI)

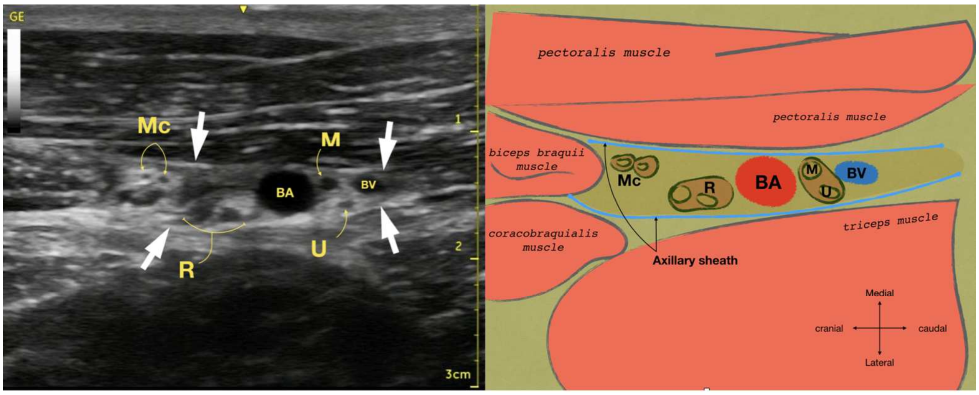

Figure 3
US image of the R, U, M, Mc nerves; from cranial to caudal Mc: musculocutaneous nerve, R: radial nerve, BA: brachial artery, U: ulnar nerve, M: median nerve, BV: brachial vein. Note the axillary sheath around the nerves (white arrows). It is possible to see the 2 Mc branches. BV is compressed and appears smaller than the BA. (B) Schematic illustration of the structures present in (A).

677x269mm (72 x 72 DPI)

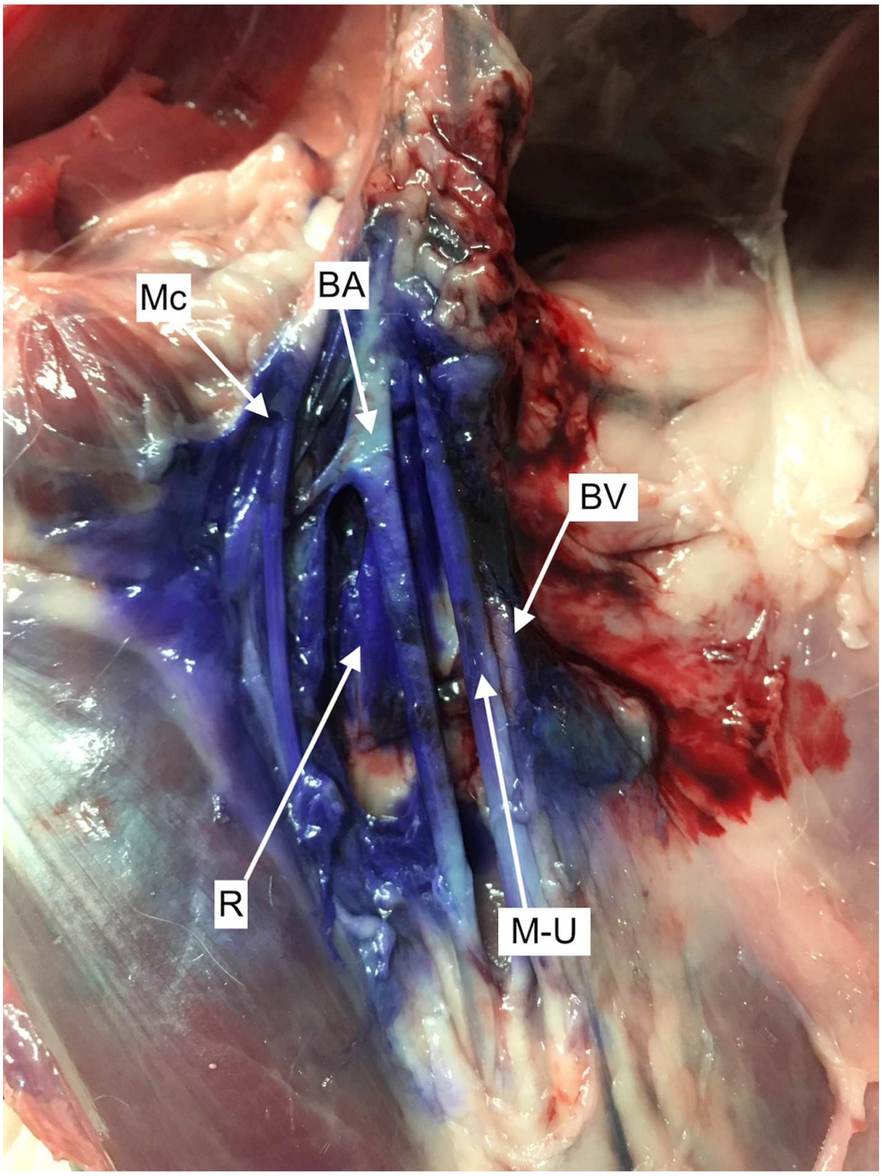

Figure 4
Staining of R, U, M, Mc nerves with new methylene blue solution. R: radial nerve, U: ulnar nerve, M: median nerve, Mc: musculocutaneous nerve, BA: brachial artery, BV: brachial vein. Note the absent of dye in the surrounding tissues.

100x134mm (300 x 300 DPI)