Equine Veterinary Journal

Equine Veterinary Journal ISSN 0425-1644
DOI: 10.1111/j.2042-3306.2012.00579.x

Function of the *ramus communicans* of the medial and lateral palmar nerves of the horse

J. SCHUMACHER*, J. TAINTOR, J. SCHUMACHER†, F. DEGRAVES‡, M. SCHRAMME§ and R. WILHITE#

Department of Clinical Sciences, Auburn University, JT Vaughan Teaching Hospital, Alabama, USA
†Large Animal Clinical Sciences, University of Tennessee, USA
‡Department of Agriculture, Western Kentucky University, USA
§Equine Clinic, National Veterinary School of Lyon, Marcy L'Etoile, France
#Department of Anatomy and Physiology, Auburn University, Alabama, USA.

*Correspondence email: schumjo@auburn.edu; Received: 01.11.11; Accepted: 20.03.12

Summary

Reasons for performing study: The role of the communicating branch between the medial and lateral palmar nerves of horses (i.e. the *ramus communicans*) in conveying sensory impulses proximally should be determined to avoid errors in interpreting diagnostic anaesthesia of the palmar nerves.
Hypothesis: Sensory nerve fibres in the *ramus communicans* of horses pass proximally from the lateral palmar nerve to merge with the medial palmar nerve, but not *vice versa*.
Objective: To determine the direction of sensory impulses through the *ramus communicans* between lateral and medial palmar nerves.
Methods: Pain in a thoracic foot was created with set-screw pressure applied to either the medial or lateral aspect of the sole of each forelimb of 6 horses. The palmar nerve on the side of the sole in which pain was created was anaesthetised proximal to the *ramus communicans* with local anaesthetic. Lameness was evaluated objectively by using a wireless, inertial, sensor-based, motion analysis system (Lameness Locator). Lameness was also evaluated subjectively by using a graded scoring system. Local anaesthetic was then administered adjacent to the *ramus communicans* to determine the effect of anaesthesia of the *ramus communicans* on residual lameness.
Results: When pain originated from the medial or the lateral aspect of the sole, anaesthesia of the ipsilateral palmar nerve proximal to the *ramus communicans* did not entirely resolve lameness. Anaesthesia of the *ramus communicans* further attenuated or resolved lameness.
Conclusions: Sensory fibres pass in both directions in the *ramus communicans* to connect the medial and lateral palmar nerves.
Potential relevance: When administering a low palmar nerve block, both palmar nerves should be anaesthetised distal to the *ramus communicans* to avoid leaving nondesensitised sensory nerve fibres passing through this neural connection. Alternatively, local anaesthetic could also be deposited adjacent to the *ramus communicans* when anaesthetising the palmar nerves.

Keywords: horse; lameness; diagnostic anaesthesia; palmar nerves; Lameness Locator

Introduction

Many clinicians recommend performing a low palmar nerve block (as part of a low 4 point nerve block) at the level of the distal aspect of the second and fourth metacarpal bones [1–4]. Because these bones vary greatly in length, medial to lateral and horse to horse [5], local anaesthetic solution may be deposited at different sites in relation to the digital flexor tendon sheath, the proximal extent of which lies at the junction of the proximal three-quarters and distal quarter of the metacarpus [5]. When performing a low palmar nerve block at the level of the distal aspect of the second and fourth metacarpal bones, the digital flexor tendon sheath is sometimes inadvertently penetrated, because it is intimately associated at its proximal extent with the fascia of the neurovascular bundle containing the palmar nerve [6,7]. Some clinicians, therefore, advise that the palmar nerves should be anaesthetised further proximally than the level of the distal aspect of the second and fourth metatarsal bones to avoid administering local anaesthetic solution inadvertently into the digital flexor tendon sheath [6,8,9]. When the lateral palmar nerve is anaesthetised more proximally to avoid the digital flexor tendon sheath, local anaesthetic solution is likely to be deposited, in many cases, proximal to the communicating nerve (i.e. the *ramus communicans*).

The basic anatomy of the palmar nerves (Fig 1) in the distal portion of the limb of horses is well described in textbooks [10,11], but to our knowledge, the physiological effects of the communicating nerve (i.e. the *ramus communicans*) between the medial and lateral palmar nerves have not been described.

Diagnostic anaesthesia of a palmar nerve distal to the site where it merges with the *ramus communicans* and anaesthesia of the contralateral palmar nerve proximal to the site where it merges with the *ramus communicans* may fail to desensitise the contralateral side of the limb distal to the *ramus communicans*. The clinical significance of the *ramus communicans* should be determined to avoid errors in interpreting diagnostic anaesthesia of the palmar nerves and to avoid sensation in the distal portion of the limb when performing regional anaesthesia for the purpose of performing surgery while the horse is conscious.

Because we observed on cadaver specimens that the medial palmar nerve is larger than the lateral palmar nerve proximal to the *ramus communicans*, we hypothesised that the sensory nerve fibres in the *ramus communicans* of the thoracic limb of horses pass proximally from the lateral palmar nerve to the medial palmar nerve. Also, we doubted that sensory nerve fibres would pass in a distal direction from the medial palmar nerve across the *ramus communicans* to the lateral palmar nerve.

Materials and methods

Horses

Six horses determined subjectively by one of the authors (Jo.S.) to have no signs of lameness of the thoracic limbs when trotted on a hard surface in a straight line were selected. The horses were aged 5–11 years (mean ± s.d. 9 ± 2 years) and weighed 457–672 kg (mean ± s.d. 531 ± 77 kg). This study was approved by Auburn University's Institutional Animal Care and Use Committee.

Temporary pain in either the medial or lateral aspect of a foot was created using a set-screw model previously described [12–14]. The horses' thoracic feet were shod with custom-made shoes to which a 2.5 cm long section of the heel of a keg shoe had been welded to the inner rim of each branch at the widest points of the shoe (Fig 2). A 9.525 mm, threaded hole was created in the centre of this axial extension. The purpose of the threaded hole in the extension was to hold a set-screw, which during the trial, was to be tightened to exert pressure on the sole to induce temporary lameness.

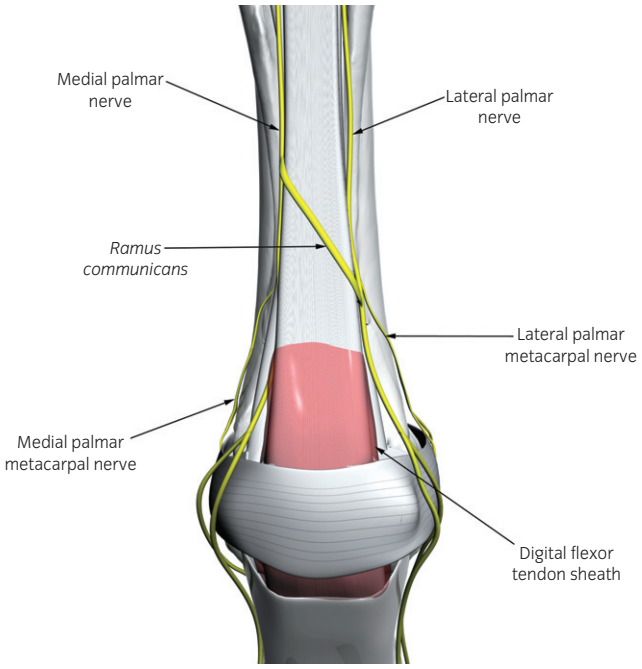

Fig 1: A right forelimb is depicted. The *ramus communicans*, which is a neural connection between the medial and lateral palmar nerves, lies subcutaneously over the superficial flexor tendon and passes proximomedially from the lateral palmar nerve to merge with the medial palmar nerve.

Evaluation of lameness

The Lameness Locator[a], a commercially available, inertial sensing device that measures asymmetry of torso motion was used to objectively quantify the degree of lameness induced and resolved in horses during the trial. The Lameness Locator uses 3 inertial sensors, attached to the dorsal aspect of the pastern of the right thoracic limb, to the centre of the poll and to the dorsal midline between the *tubera sacralia*. The purpose of the sensors is to detect and quantify lameness by recording torso motion and by calculating the means and standard deviations of maximum and minimum differences in height of the head (for forelimb evaluation) and pelvis (for hindlimb evaluation) between left and right halves of the stride. Identification of lameness to the right or left thoracic limb within the stride is determined by the association of head movement with the angular velocity of the right thoracic limb [15]. Maximum (MAXDIFFHEAD) and minimum (MINDIFFHEAD) head height differences in mm between right and left halves of the stride are generated by the device. Amplitude of the vector sum (VS) of MAXDIFFHEAD and MINDIFFHEAD correlates with severity of lameness, with a value of approximately 6 mm as a threshold between lame and sound [16]. Results of recent studies indicate that this inertial sensor system provides appropriate accuracy and sensitivity for clinical use [16,17].

Gait before and after inducing lameness and after administering regional anaesthesia was subjectively evaluated by 2 of the authors (Jo.S. and Ji.S.) while viewing randomised video recordings as the horses were trotted in a straight line for about 82 m. One of the authors (Jo.S.) had observed the gaits during recordings while using the Lameness Locator, but the other evaluator (Ji.S.) had not. For subjective grading, a lameness scale of 0–10 was used in which 10 represented a nonweightbearing lameness of one limb, 1 a barely discernible lameness, and 0 a sound limb [18].

Procedure

A summary of the regional anaesthetic procedures is depicted in Figure 3. After randomly selecting a limb and before applying the set-screw, a randomly selected side of the foot chosen not to receive the set-screw was desensitised by administering 2.5 ml of 2% mepivacaine hydrochloride (Carbocaine-V)[b] adjacent to the palmar digital nerve at the base of the ipsilateral proximal sesamoid bone. This nerve block was performed to ensure that the set-screw caused pain only in the portion of the sole (medial or lateral) to which it was applied. Efficacy of this nerve block was evaluated approximately 5 min later by checking for loss of skin sensation at the coronet on the side of the foot that was desensitised. The horse was then trotted in a straight line for approximately 25 strides while the symmetry of its gait was evaluated objectively with the Lameness Locator (first, or base-line, evaluation) and subjectively evaluated later by viewing randomised, unlabelled video recordings. For each horse, lameness was created by applying a set-screw to the selected medial or lateral aspect of the sole of the foot. At another time, a set-screw was applied to the opposite aspect of the sole of the contralateral thoracic limb. After recording the base-line gait, a set-screw was applied to the nondesensitised portion of the sole until lameness was created that was consistent and easy to detect and that caused subjectively detectable head nodding when the horse was trotted in a straight line on a hard surface. The set-screw was applied to firmly contact, but not penetrate, the sole. Symmetry of the horse's gait was again objectively (and later, subjectively) evaluated while the horse trotted (second evaluation).

The palmar nerve ipsilateral to the side of the foot subjected to set-screw pressure was anaesthetised with 2.5 ml of mepivacaine hydrochloride administered 2 cm or more proximal to the point at which the *ramus communicans* was palpated to merge with the palmar nerve. Ten minutes later, symmetry of the horse's gait was again evaluated objectively (and later, subjectively) while the horse trotted (third evaluation). Every horse was determined to have residual lameness based on visual, subjective evaluation and by examining data generated by the Lameness Locator, and to eliminate this residual lameness, the *ramus communicans* was anaesthetised with 1 ml of mepivacaine hydrochloride administered subcutaneously close to where it merged with the palmar nerve that had been previously anaesthetised. After 5–6 min, symmetry of gait was again evaluated objectively (and later, subjectively) while the horse trotted (fourth evaluation). After the fourth evaluation, the set-screw was removed from the shoe.

After lameness had been abolished in that limb (by removing the set-screw and by regional anaesthesia), as determined with the Lameness Locator, the same procedures were performed on the contralateral

Fig 2: Thoracic feet were shod with custom-made shoes to which a 2.5 cm long section of the heel of a keg shoe had been welded to the inner rim of each branch at the widest points of the shoe. A 9.525 mm, threaded hole was created in the centre of this axial extension for the purpose of holding a set-screw, which was tightened to place pressure on the sole to induce temporary lameness.

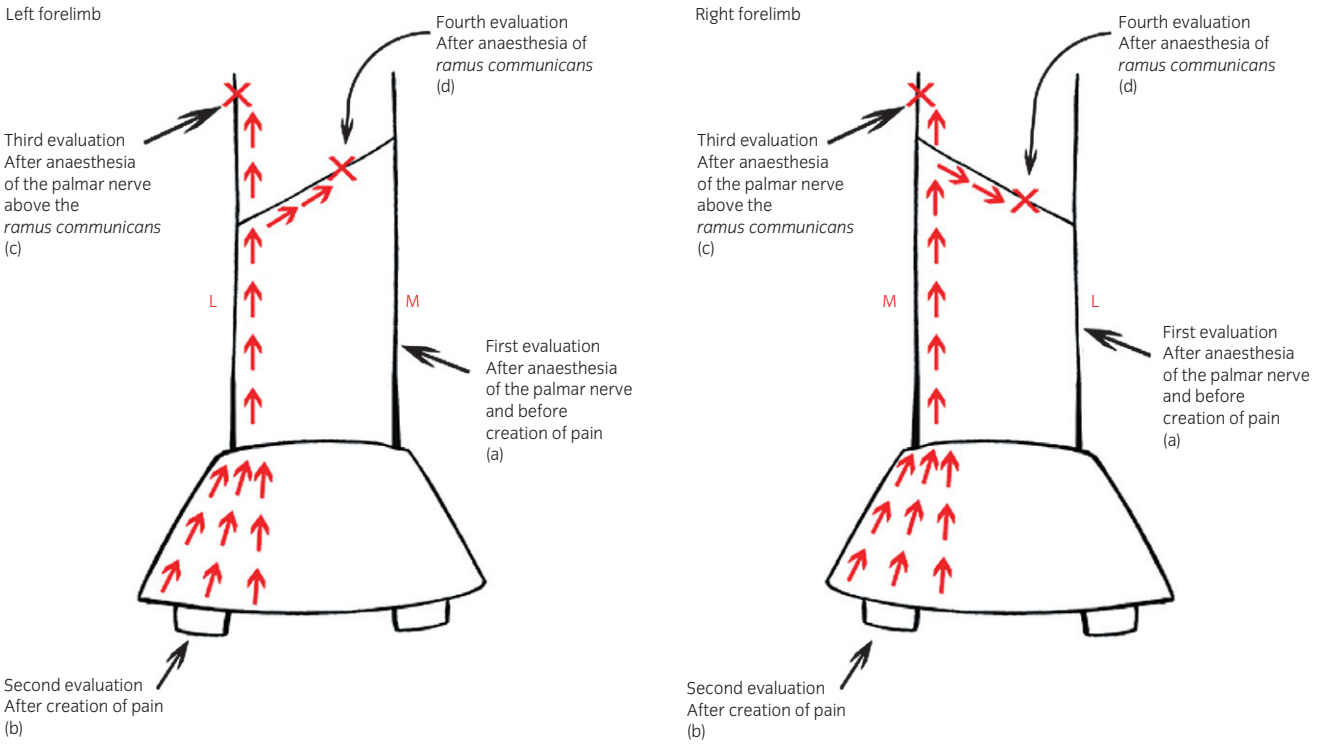

Fig 3: After anaesthetising the palmar nerve on a randomly selected side of the foot (a), lameness in a thoracic limb was created by applying a set-screw to the opposite side of the sole (b). After determining the degree of lameness caused by set-screw pressure, the palmar nerve on the side of the foot that received the set-screw was blocked ~2 cm proximal to point at which the *ramus communicans* merged with that palmar nerve (c). After determining the degree of lameness after the palmar nerve block above the *ramus communicans*, the *ramus communicans* was anaesthetised (d) by administering local anaesthetic solution subcutaneously over this nerve and the degree of lameness was again determined.

thoracic limb, but on the opposite side of that limb. After 10–14 days, the procedures were repeated, but the opposite aspects of each foot received set-screw pressure so that each horse was subjected at different times to set-screw pressure applied both medially and laterally to the sole of each thoracic foot to test the ability of the *ramus communicans* to carry sensory impulses in medial and lateral directions.

Data recorded from the Lameness Locator

Data collected by the Lameness Locator were processed and analysed as previously described [15–17,19]. Severity of the lameness was determined by calculating the vector sum (VS) determined from data obtained using the Lameness Locator. The vector sum (VS) of MAXDIFFHEAD and MINDIFFHEAD gives an overall measure of asymmetry of vertical movement of the head that takes into consideration both upward and downward asymmetries of movement. The vector sum (VS) was determined from data collected while horses were trotting before applying the set-screw, after applying the set-screw, after injecting local anaesthetic solution adjacent to the palmar nerve on the side of set-screw application proximal to the *ramus communicans*, and after injecting local anaesthetic solution adjacent to the *ramus communicans*.

Data analysis

Vector sum of MAXDIFFHEAD and MINDIFFHEAD in mm were calculated from all trials. The VS was modelled using repeated measures analysis after evaluating residual plots for normality of data (PROC MIXED, SAS 9.1)[c]. The VS data were subjected to a log10 transformation to approximate a normal distribution. Correlated data were accounted for using the following linear model [20–22]:

$$Y = X\beta + Z\mu + e$$

where Y was the vector of observations, X was the treatment design matrix (lateral and medial palmar nerve; left and right limb; first, second, third, fourth evaluations), β was the vector of fixed treatment effects, Z was the random effects design matrix (horse), μ was the vector of random block effects, and e was the vector of experimental error. To account for the nonindependence of observations within horses, 5 correlation structures were tested (compound symmetry, first order autoregressive, spatial power law, unstructured, and variance components) [20–22]. Models were compared using Akaike's information criterion [20–22]. Horse was included in models as a random effect [20–22]. The Kenward-Roger correction was used for all models [20–22]. The P values of multiple comparisons were adjusted using Tukey-Kramer method [23]. Subjective data were modelled using generalised estimating equation methodology for repeated measures (PROC GENMOD, SAS 9.1). Lateral and medial palmar nerve; left and right limb; first, second, third, and fourth evaluations; and first and second observers were evaluated in models as independent variables. Subjective lameness scores were included as dependent variables. The independence model was used for working correlation structure with multinomial distribution [24]. P values ≤ 0.05 were considered significantly different.

Results

Subjective data and those obtained with the Lameness Locator for one limb of one horse were not used for the analysis because, subjectively and on examination of data generated by the Lameness Locator, the gait appeared not to have changed between the second (after application of the set-screw) and third (after a palmar nerve block) evaluations, indicating that the medial palmar nerve block was incomplete. The Lameness Locator records the time of each gait analysis. The time recorded from gait analysis after application of the set-screw to gait analysis after anaesthesia of the *ramus communicans* ranged from 17–34 min (median, 23 min). Based on subjective evaluation of gait in other studies in which lameness was created by causing solar pressure with a set-screw [12,14], the degree of lameness caused by the set-screw does not appear to diminish during the period of time gaits of horses in our study were evaluated.

Compound symmetry was selected as the correlation structure for VS models. There was no significant difference in VS after anaesthesia of the

TABLE 1: Severity of the lameness of 6 horses was determined by calculating the vector sum (VS) determined from data obtained using the Lameness Locator for evaluation of each horse while trotting before applying the set-screw, after applying the set-screw, after injecting local anaesthetic solution adjacent to the palmar nerve on the side of set-screw application proximal to the *ramus communicans*, and after injecting local anaesthetic solution adjacent to the *ramus communicans*

	Vector sum (amplitude) of lameness (mm) Mean ± s.d.		
Test condition	Lateral palmer nerve block	Medial palmar nerve block	Lateral and medial palmar nerve blocks
Pre-set-screw	7.56 ± 5.90	8.36 ± 4.86	7.95 ± 5.44[a]
Post set-screw	71.0 ± 31.7	82.3 ± 29.7	76.4 ± 31.3[b]
Post palmar nerve block	41.0 ± 26.0	32.4 ± 33.4	36.9 ± 30.1[c]
Post ramus block	7.44 ± 5.70	17.0 ± 16.2	12.0 ± 12.9[a]

Means with different superscript letters are significantly different.

ramus communicans between limbs with pain created in the medial or lateral aspect of the foot (P = 0.531), indicating that sensory nerves from both the lateral and the medial palmar nerves branch pass through the *ramus communicans*. Consequently, medial or lateral aspect of the hoof was dropped as an independent variable from the final model. There were also no significant differences in VS of gait after anaesthetising the ipsilateral palmar nerve and in VS after anaesthesia of the *ramus communicans* between right and left limbs (P = 0.678), indicating that both medial and lateral palmar nerves are symmetrical in function with respect to left and right side of the body. Because of this lack of significant difference, right or left limb was also dropped as an independent variable from the final model.

Vector sum of gait after application of the set-screw was significantly different from VS of gait before application of the set-screw (P<0.0001), indicating successful implementation of set-screw-induced solar pain. Vector sum of gait after anaesthetising the ipsilateral palmar nerve to the side of pain induction was significantly different from VS of gait after application of set-screw (P<0.0001), indicating that sensory nerves innervating the sole passed through the palmar nerves. For all horses, lameness was detected both subjectively and by examination of data generated by the Lameness Locator after anaesthetising the palmar nerve above the *ramus communicans*. Vector sum of gait after anaesthesia of the *ramus communicans* was significantly different from VS of gait after anaesthetising the palmar nerve (P = 0.0014), indicating that branches from palmar nerves pass through the *ramus communicans*. Results of data obtained using the Lameness Locator are summarised in Table 1.

Subjective data supported objective data (Table 2). There were no significant differences in subjective lameness scores between limbs with pain in the medial or lateral aspect of the foot (P = 0.583) or between right or left limbs (P = 0.948), and both of these independent variables were dropped from the final model. There was no significant difference in lameness scores assigned by the 2 observers (P = 0.706), and this independent variable was also dropped from the final model.

Lameness scores of gait subjectively evaluated after application of the set-screw were significantly different from scores of gait evaluated before application of the set-screw (P = 0.0171); subjective scores of gait evaluated after anaesthetising the ipsilateral palmar nerve were significantly different from scores of gait evaluated after application of the set-screw (P = 0.0257), and subjective scores of gait evaluated after anaesthesia of the *ramus communicans* improved (and tended towards significance, P = 0.0660) over scores assigned to gait after anaesthetising the palmar nerve. Results of data obtained subjectively are summarised in Table 2.

Discussion

Our hypothesis that sensory nerve impulses pass across the *ramus communicans* only from the lateral palmar nerve to the medial palmar nerve proved to be incorrect. Data from this study indicate that sensory nerve fibres in the medial palmar nerve pass distolaterally across the *ramus communicans* to the lateral palmar nerve and that sensory nerve fibres in the lateral palmar nerve pass proximomedially across the *ramus communicans* to the medial palmar nerve. When pain originated from the medial or the lateral aspect of the sole, anaesthesia of the ipsilateral palmar nerve proximal to the *ramus communicans* did not entirely resolve lameness. Anaesthesia of the *ramus communicans* further attenuated or resolved lameness indicating that nerve impulses pass in both directions across this neural connection. We found 1 ml of local anaesthetic solution to be sufficient for anaesthetising the *ramus communicans* in the forelimb because the nerve is small but easily palpated, allowing for accurate deposition of anaesthetic solution adjacent to the nerve. The Lameness Locator appeared to be a more sensitive indicator of lameness than was subjective evaluation of videotaped segments of gait. For example, differences between the subjective lameness scores after anaesthetising the palmar nerve and subjective lameness scores after anaesthetising the *ramus communicans* were not significant (P = 0.0660); when using objective data from the Lameness Locator, however, these differences were highly significant (P<0.0001). Also, P values for other subjective comparisons that were just barely significant were found to be highly significant when using objective data.

TABLE 2: Subjective lameness scores of 6 horses were determined while viewing videotapes of each horse while trotting before applying the set-screw, after applying the set-screw, after injecting local anaesthetic solution adjacent to the palmar nerve proximal to the *ramus communicans*, on the side of set-screw application, and after injecting local anaesthetic solution adjacent to the *ramus communicans*

	Subjective scores Median (range)		
Test condition	Lateral palmar block	Medial palmar block	Lateral and medial palmar nerve blocks
Pre-set-screw	0.5 (0–3)	0.5 (0–3)	0.5 (0–3)[a]
Post set-screw	5 (3–8)	6.5 (2–9)	6 (2–9)[b]
Post palmar nerve block	2 (0–7)	3 (0–6)	2 (0–7)[c]
Post ramus block	2 (0–3)	1.5 (0–4)	2 (0–4)[ac]

Medians with different superscript letters are significantly different.

When a low palmar nerve block is performed more proximally in the limb, many clinicians advise that the medial and lateral palmar nerves should be anaesthetised distal to the *ramus communicans* [9,25]. This neural branch passes proximally and obliquely from the lateral palmar nerve near the junction of distal and middle thirds of the metacarpus and merges with the medial palmar nerve near the middle of the metacarpus [26]. Because the location at which the *ramus communicans* merges with the medial palmar nerve is further proximal on the limb than the location at which it merges with the lateral palmar nerve, a low, medial palmar nerve block at the middle of the metacarpus would be likely to result in local anaesthetic solution being administered adjacent to the medial palmar nerve at or distal to the site where it merges with the *ramus communicans* (authors' observation). When depositing local anaesthetic solution more proximal on the limb to avoid the digital flexor tendon sheath while performing a low, lateral palmar nerve block, local anaesthetic solution is quite likely to be administered proximal to the site where the communicating branch merges with the lateral palmar nerve. This study shows that anaesthetising a palmar nerve proximal to the *ramus communicans* on one side of the metacarpus and anaesthetising the palmar nerve distal to the *ramus communicans* on the other may result in incomplete desensitisation of a distal lesion causing lameness, which could result in an erroneous conclusion concerning the site of pain causing lameness.

Because local anaesthetic solution may migrate proximally over time after perineural injection of the palmar nerves resulting in inadvertent and unrecognised desensitisation of more proximal structures [7,27], we also recommend that when administering a low palmar nerve block, both palmar nerves be anaesthetised distal (rather than proximal) to the *ramus communicans* [9,25]. Injecting distal to the *ramus communicans* without risk of injecting the digital flexor tendon sheath may be difficult when anaesthetising the lateral palmar nerve at the level of the distal aspect of the fourth metacarpal bone. In that case, a small quantity of local anaesthetic solution (e.g. 1 ml) can be deposited adjacent to the *ramus communicans* to avoid transfer of sensory impulses from one palmar nerve to the other.

Authors' declaration of interests

No conflicts of interest have been declared.

Source of funding

Birmingham Racing Commission, Birmingham, Alabama, USA.

Acknowledgements

We are grateful to Mrs Sharon Peterson, Columbus, Ohio for the donation of the Lameness Locator.

Manufacturers' addresses

[a]Equinosis LLC, Columbia, Missouri, USA.
[b]Carbocaine-V, Pfizer, Inc., New York, New York, USA.
[c]SAS Institute Inc., Cary, North Carolina, USA.

References

1. Schmotzer, W.B. and Timm, K.I. (1990) Local anesthetic techniques for diagnosis of lameness. *Vet. Clin. N. Am.: Equine Pract*. **6**, 705–728.
2. Carter, G.K. and Hogan, P.M. (1996) Use of diagnostic nerve blocks in lameness evaluation. *Proc. Am. Ass. Equine Practnrs*. **42**, 26–32.
3. Stashak, T.S. (2002) Examination for lameness. In: *Adams' Lameness in Horses*, 5th edn., Ed: T.S. Stashak, Lea and Febiger, Philadelphia. pp 113–183.
4. Bassage, L.H. and Ross, M.W. (2003) Diagnostic analgesia. In: *Diagnosis and Management of Lameness in the Horse*, Eds: M.W. Ross and S.J. Dyson, Elsevier Science, St Louis. pp 93–124.
5. Getty, R. (1975) Equine osteology. In: *Sisson and Grossman's The Anatomy of Domestic Animals*, 5th edn., Ed: R. Getty, W.B. Saunders, Philadelphia. pp 255–348.
6. Amend, K.S., Selberg, K.T., Valdes-Martinez, A. and Baxter, G.M. (2009) Diffusion of anesthetic after a low palmar nerve block. *Proc. Am. Ass. Equine Practnrs*. **55**, 229.
7. Nagy, A., Bodo, G., Dyson, S.J., Compostella, F. and Barr, A.R.S. (2010) Distribution of radiodense contrast medium after perineural injection of the palmar and palmar metacarpal nerves (low 4-point nerve block): an *in vivo* and *ex vivo* study in horses. *Equine Vet. J.* **42**, 512–518.
8. Dyson, S.J. (1984) Nerve blocks and lameness diagnosis in the horse. *In Pract*. **6**, 102–107.
9. Moyer, W., Schumacher, J. and Schumacher, J. (2011) *Equine Joint Injection and Regional Anesthesia*, Academic Veterinary Solutions, Chadds Ford. pp 102–103.
10. König, H.E., Liebich, H.-G. and Ćerveny, C. (2009) Nervous system. In: *Veterinary Anatomy of Domestic Mammals*, 4th edn., Eds: H.E. Konig and H.-G. Liebich, Schattauer, New York. pp 489–560.
11. Dyce, K.M., Sack, W.O. and Wensing, C.J.G. (2010) *Textbook of Veterinary Anatomy*, 4th edn., W.B. Saunders, St Louis. p 623.
12. Schumacher, J., Schumacher, J., DeGraves, F., Steiger, R., Schramme, M., Smith, R. and Coker, M. (2001) A comparison of the effects of two volumes of local analgesic solution in the distal interphalangeal joint of horses with lameness caused by solar toe or solar heel pain. *Equine Vet. J.* **33**, 265–268.
13. Schumacher, J., Steiger, R., Schumacher, J., Schramme, M., DeGraves, F., Smith, R. and Coker, M. (2000) Effects of analgesia of the distal interphalangeal joint or palmar digital nerves on lameness caused by solar pain in horses. *Vet. Surg*. **29**, 54–58.
14. Harper, J., Schumacher, J., DeGraves, F., Schramme, M. and Schumacher, J. (2007) Effects of analgesia of the digital flexor tendon sheath on pain originating in the sole, distal interphalangeal joint or navicular bursa of horses. *Equine Vet. J.* **39**, 535–539.
15. Keegan, K.G., Yonezawa, Y., Pai, P.F., Wilson, D.A. and Kramer, J. (2004) Sensor based system of equine motion analysis for the detection and quantification of forelimb and hindlimb lameness in horses. *Am. J. Vet. Res*. **65**, 665–670.
16. Keegan, K.G., MacAllister, C.G., Wilson, D.A., Gedon, C.A., Kramer, J., Yonezawa, Y., Maki, H. and Pai, F. (2012) Comparison of an inertial sensor system to the stationary force plate for evaluation of horses with bilateral forelimb lameness. *Am. J. Vet. Res*. **73**, 368–374.
17. Keegan, K.G., Kramer, J., Yonezawa, Y., Maki, H., Pai, P.F., Dent, E.V., Kellerman, T.E., Wilson, D.A. and Reed, S.K. (2011) Assessment of repeatability of a wireless inertial sensor-based lameness evaluation system for horses. *Am. J. Vet. Res*. **72**, 1156–1163.
18. Wright, I.M. (1993) A study of 118 cases of navicular disease: clinical features. *Equine Vet. J.* **25**, 488–492.
19. Keegan, K.G., Pai, P.F., Wilson, D.A. and Smith, B.K. (2001) Signal decomposition method of evaluating head movement to measure induced forelimb lameness in horses trotting on a treadmill. *Equine Vet. J.* **33**, 446–451.
20. Littell, R.C., Henry, P.R. and Ammerman, C.B. (1998) Statistical analysis of repeated measures data using SAS procedures. *J. Anim. Sci*. **76**, 1216–1231.
21. Littell, R.C., Pendergast, J. and Natarajan, R. (2000) Modelling covariance structure in the analysis of repeated measures data. *Stat. Med*. **19**, 1793–1819.
22. Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D. and Schabenberger, O. (2006) *SAS for Mixed Models*, 2nd edn., SAS Institute Inc, Cary.
23. Westfall, P.H., Tobias, R.D., Rom, D., Wolfinger, R.D. and Hochberg, Y. (1999) *Multiple Comparisons and Multiple Tests Using the SAS System*, SAS Institute Inc, Cary.
24. Stokes, M.E., Davis, E., Charles, S. and Koch, G.G. (1995) *Categorical Data AnalysisUsing the SAS System*, SAS Institute Inc, Cary. p 499.
25. Barr, A.R.S. (1997) Local analgesia. In: *Diagnostic Techniques in Equine Medicine*, Eds: F.G.R. Taylor and M.H. Hillyer, W.B. Saunders, London. pp 231–270.
26. Kainer, R.A. (2002) Fuctional anatomy of equine locomotor organs. In: *Adams' Lameness in Horses*, 5th edn., Ed: T.S. Stashak, Lea and Febiger, Philadelphia. pp 1–72.
27. Nagy, A., Bodo, G., Dyson, S.J., Szabo, F. and Barr, A.R.S. (2009) Diffusion of contrast medium after perineural injection of the palmar nerves: an *in vivo* and *in vitro* study. *Equine Vet. J.* **41**, 379–383.