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Neurovascular variations in the proximal plantar metatarsal region of the horse

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Abstract:	BACKGROUND: Neurovascular variation may be relevant when performing surgical techniques to the proximal plantar metatarsal region. OBJECTIVES: To document variations in the neurovascular anatomy of the proximal plantar metatarsal region and study the relationship of the neurovascular components to each other and other structures located in this area. STUDY DESIGN: Descriptive anatomical study. METHODS: Paired cadaver hind limbs from 15 horses were dissected from the distal tibia to the metatarsophalangeal joint. Deep branch of the lateral plantar nerve (DBLPN) length, location of its origin from the lateral plantar nerve (LPN), individual DBLPN ramifications into the suspensory ligament (SL) and relationship of the DBLPN to the plantar arch and accessory ligament of the deep digital flexor tendon (ALDDFT) were recorded. RESULTS: Mean DBLPN length was 5.8 ± 1.7 cm with the nerve arising 3.7 ± 1.5 cm proximal to the head of the fourth metatarsal bone (MTIV). There was a median of 3 individual DBLPN ramifications (range 2-6) entering the SL. There were no significant left/right differences. In 57% (CI 39-74%; n=17) limbs, the deep plantar arch was superficial to the DBLPN whereas in 33% (CI 16-50%; n=10) limbs the DBLPN passed between the venous and arterial components of the arch. In 10% (CI 1-20%; n=3) limbs the deep plantar arch was deep to the DBLPN. In 67% (CI 50-84%; n=20) limbs the DBLPN was superficial to the ALDDFT where in 33% (CI 16-50%; n=10) limbs the nerve ran deep to the ALDDFT. An additional branch from the LPN was noted in one limb. MAIN LIMITATIONS: Limbs were used from horses with unknown clinical history. CONCLUSIONS: Anatomical variation, in particular the relationship of the DBLPN and deep metatarsal fascia to the deep plantar arch and the ALDDFT is an important consideration when undertaking surgical approaches to the proximal plantar metatarsal region.

ABSTRACT

BACKGROUND: Neurovascular variation may be relevant when performing surgical techniques to the proximal plantar metatarsal region.

OBJECTIVES: To document variations in the neurovascular anatomy of the proximal plantar metatarsal region and study the relationship of the neurovascular components to each other and other structures located in this area.

STUDY DESIGN: Descriptive anatomical study.

METHODS: Paired cadaver hind limbs from 15 horses were dissected from the distal tibia to the metatarsophalangeal joint. Deep branch of the lateral plantar nerve (DBLPN) length, location of its origin from the lateral plantar nerve (LPN), individual DBLPN ramifications into the suspensory ligament (SL) and relationship of the DBLPN to the plantar arch and accessory ligament of the deep digital flexor tendon (ALDDFT) were recorded.

RESULTS: Mean DBLPN length was 5.8 ± 1.7 cm with the nerve arising 3.7 ± 1.5 cm proximal to the head of the fourth metatarsal bone (MTIV). There was a median of 3 individual DBLPN ramifications (range 2-6) entering the SL. There were no significant left/right differences. In 57% (CI 39-74%; n=17) limbs, the deep plantar arch was superficial to the DBLPN whereas in 33% (CI 16-50%; n=10) limbs the DBLPN passed between the venous and arterial components of the arch. In 10% (CI 1-20%; n=3) limbs the deep plantar arch was deep to the DBLPN. In 67% (CI 50-84%; n=20) limbs the DBLPN was superficial to the ALDDFT where in 33% (CI 16-50%; n=10) limbs the nerve ran deep to the ALDDFT. An additional branch from the LPN was noted in one limb.

MAIN LIMITATIONS: Limbs were used from horses with unknown clinical history.

CONCLUSIONS: Anatomical variation, in particular the relationship of the DBLPN and deep metatarsal fascia to the deep plantar arch and the ALDDFT is an important consideration when undertaking surgical approaches to the proximal plantar metatarsal region.

KEYWORDS: “Horse”; “Nerves and blood vessels”; “Suspensory ligament”

INTRODUCTION

An understanding of the neurovascular anatomy of the proximal plantar metatarsal region of the horse is important when considering surgical management of conditions associated with that region. The deep branch of the lateral plantar nerve (DBLPN), arising from the lateral plantar nerve (LPN), provides innervation to the suspensory ligament (SL) as well as contributing to the lateral and medial plantar metatarsal nerves.[1] The length of the DBLPN from its origin and subsequent ramification has been described in 10 cadaver limbs with a second branch noted in one specimen.[2] This study also described the DBLPN as passing immediately deep to transverse vascular bundle, known as the deep plantar arch, in all samples studied. The deep plantar arch (NAV *arcus plantaris profundus*) is formed from the union of the perforating tarsal artery with the plantar arteries, with the plantar veins forming a corresponding venous arch from the anastomoses of lateral and medial plantar vessels.[1] However, variation of the vascular elements in the region has received less attention and this with nerve variation, if present, could be important considerations in surgery.

Removal of a section of the DBLPN with or without sectioning of the deep metatarsal fascia (fasciotomy) has been described as an effective treatment for desmitis of the proximal portion of the SL. [3-5] The rationale for neurectomy is based on the presence of compressive damage to the DBPLN in clinical cases, as described by Toth et al.,[6] but also possibly through inducing local neurogenic atrophy of remaining muscle fibres in the proximal portion of the SL as documented in the fore limb.[7] Fasciotomy of the deep metatarsal fascia on the plantar aspect of the SL is often combined with neurectomy in a bid to relieve pressure to the adjacent SL, akin to releasing procedures in compartment-like syndrome.[6,8] Often this procedure is performed blind in a proximal-to-distal direction using scissors or a fasciotome, although the

proximity of this fascia to other nearby structures such as the accessory ligament of the deep digital flexor tendon (ALDDFT) or the deep plantar arch as well as the SL may not be appreciable during surgery, thereby risking iatrogenic injury.[3]

The aims of this study were to describe and characterise the neurovascular anatomy of the plantar metatarsal region and to document variations present in the relationship of the neurovascular components to each other and other structures located in this area. Our hypothesis was that neurovascular anatomy of the proximal plantar metatarsal region was comparable in horses and between limbs.

MATERIALS AND METHODS

Paired cadaver hind limbs were used from 15 similar sized horses (n=30 limbs) of unknown history and euthanized for reasons unrelated to this project. Limbs were sectioned approximately 30cm proximal to the point of the calcaneus. Samples used in this study were acquired as a by-product of the agricultural industry and utilised within Institute Ethical Approval RETH000553 (approval date 02.07.2015). Limbs were dissected from the distal tibia to the level of the metatarsophalangeal joint. To access the deeper plantar metatarsal structures, the superficial digital flexor tendon (SDFT) and deep digital flexor tendon (DDFT) were sectioned and reflected in a proximal and distal direction.

The prominence of the head of the fourth metatarsal bone (MTIV) was taken as a fixed reference point (based on previous work)[2] with the distance proximal or distal to this recorded for the following variables: location of bifurcation of DBLPN from LPN and distance to the

proximal border of the deep metatarsal fascia. Other data recorded were number of nerve branches from the LPN, length of DBLPN (measured from its origin from the LPN to its entry into the SL)[2] and number of individual DBLPN ramifications on entry into the SL. In addition, the relationship of the DBLPN to the position of the deep plantar arch and accessory ligament of the deep digital flexor tendon (ALDDFT) was described. Data were recorded as mean (± SD) or median (plus range) with 95% confidence intervals reported for sample proportions. Paired student's t-test was used to test left/right differences with significance level of $P<0.05$.

RESULTS

All limbs contained a DBLPN with no evidence of previous surgical intervention. In addition, no adhesions or other gross pathology were noted in the samples evaluated. Mean DBLPN length was 5.8. ± 1.7 cm with a mean distance from the head of MTIV (proximally) to bifurcation from the LPN of 3.7 ± 1.5 cm. There was a median of 3 individual DBLPN ramifications (range 2-6) entering the SL (Figures 1 and 2). The distance from head of MTIV to the proximal border of the deep metatarsal fascia was 2.4 ± 0.5 cm. There were no significant left/right differences recorded for these data (all $P > 0.05$). In all samples the deep plantar arch coursed just proximal to the proximal border of the deep metatarsal fascia.

In 57% (CI 39-74%; n=17) of samples the deep plantar arch coursed over the DBLPN whereas in 33% (CI 16-50%; n=10) of cases the DBLPN passed superficial to the venous but deep to the arterial components of the deep plantar arch.) In 10% of limbs (CI 1-20%; n=3) the DBLPN ran superficial to all components of the deep plantar arch (Figure 3). Comparing left to right, only 40% (CI 15-65%; n=6) pairs showed the same relationship of the DBLPN to the deep plantar arch in both hind limbs.

The relationship of the DBLPN to the ALDDFT revealed that in 67% (CI 50-84%; n=20) of samples, the DBLPN was superficial to the ALDDFT. In 33% limbs (CI 16-50%; n=10) the DBLPN coursed deep to the ALDDT. In 60% (CI 35-85%; n=9) pairs the relationship of the DBLPN and the ALDDFT was the same in the left and right limb.

In only one limb an additional branch from the LPN was noted with the ALDDFT positioned between the two branches (Figure 4). Finally, in one limb a substantive ALDDFT obscured the proximal margin of the SL fascia and plantar arch (Figure 5a and b).

DISCUSSION

Despite being often reported in the digit as a possible reason for poor response to local anaesthesia or following neurectomy,[9-12] there was little nerve variation of the DBLPN in the present study. The majority of limbs (97%; 29/30) contained only one DBLPN, similar to that reported in 90% (9/10) of cadaver limbs and in 95% of clinical cases at surgery.[2,3] The DBPLN consistently provides exclusive innervation to the proximal portion of the suspensory ligament and therefore correct identification and removal of a section of the DBPLN should lead to successful neurectomy to the proximal portion of the SL.[1,3-5]

The relationship of the DBLPN to the deep plantar arch, however, varied between horses and also between limbs unlike previously reported where the entry of the DBLPN into the proximal portion of the SL was always deep to the plantar arch.[2] The most common relationship (~60%) was that the nerve coursed deep to the deep plantar arch although in one-third of limbs the

nerve ran between the arterial and venous components of the arch. In only three limbs (10%) did the nerve run superficial to the deep plantar arch. Since the level of the deep plantar arch appeared close to where the DBLPN ramified into the SL and with the site for neurectomy of the nerve commonly proximal to this, the nerve should be able to be accessed and removed safely without compromise to the vessels, although in *in vivo*, engorgement of the vessels could potentially hinder this.

A more pressing concern is safe access to the deep metatarsal fascia; this study highlighted the proximity of the deep plantar arch to the proximal border of the deep metatarsal fascia and the influence of the location of the ALDDFT in visualising the area. In one specimen in particular, a substantive ALDDFT lay over the proximal margin of the deep metatarsal fascia and the deep plantar arch (Figure 5a and b). Although the DBLPN could be located branching normally from the LPN and ran along the lateral margin of the ALDDFT, the nerve then ran under the ALDDFT and plantar arch before entering the SL. Removal of a portion of nerve should still be achievable, however, the size and location of the ALDDFT in this specimen would make sectioning of the deep metatarsal fascia very difficult to achieve. In this scenario there may also be increased risk of iatrogenic damage to the deep plantar arch as well as the ALDDFT. Iatrogenic damage is clearly an undesirable surgical outcome and could result in post-operative morbidity (for example haemorrhage, swelling, surgical site infection, adhesion formation, recurrent lameness). Post-operative damage to the SL has been reported by Dyson and Murray[3] and adhesion formation has also been described both pre- and post-operatively between the SL and ALDDFT in cases refractory to surgical management.[14] The use of a fasciotome rather than scissors was noted to result in less iatrogenic trauma to the SL although this did not prevent injury *per se.*[13]

Limitations of this study include the lack of clinical history of the horses the specimens were obtained from, although no gross abnormalities or evidence for previous surgical intervention was noted. Additional samples could also augment the findings presented in this study.

In conclusion, anatomical variation, in particular the relationship of the DBLPN to the plantar arch and ALDDFT, is an important consideration when undertaking surgical approaches to the proximal plantar metatarsal region in the horse. A note of caution should also be struck from the lack of comparability between paired limbs, as highlighted in this study, particularly where bilateral surgical procedures are commonly performed. Operators should consider that anatomical arrangement in one limb is not a reflection of the other and that each limb should be considered independent in this matter.

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Figure Legends

Figure 1

Example showing the location of the deep branch of the lateral plantar nerve (DBLPN) and its branches deep to the deep plantar arch in the left hind limb. The limb is orientated as though the horse were in dorsal recumbency. Lateral is to the left and distal is to the top of the image. LPN = lateral plantar nerve, SL = suspensory ligament. Scale bar = 5mm. *This image has been reversed for comparative purposes.*

Figure 2

Example showing the course of the deep branch of the lateral plantar nerve (DPBLN) in the right hind limb after the deep plantar arch has been cut, showing the relationship of the nerve to the accessory ligament of the deep digital flexor tendon (ALDDFT) and proximal margin of the deep metatarsal fascia. The limb is orientated as though the horse were in dorsal recumbency. Lateral is to the left and distal is to the top of the image. LPN = lateral plantar nerve. Scale bar = 5mm.

Figure 3

Example showing the deep branch of the lateral plantar nerve (DBLPN) and its branches superficial to the deep plantar arch in the right hind limb. The limb is orientated as though the horse were in dorsal recumbency. Lateral is to the left and distal is to the top of the image. a = artery, v = vein, SL = suspensory ligament, Scale bar = 5mm.

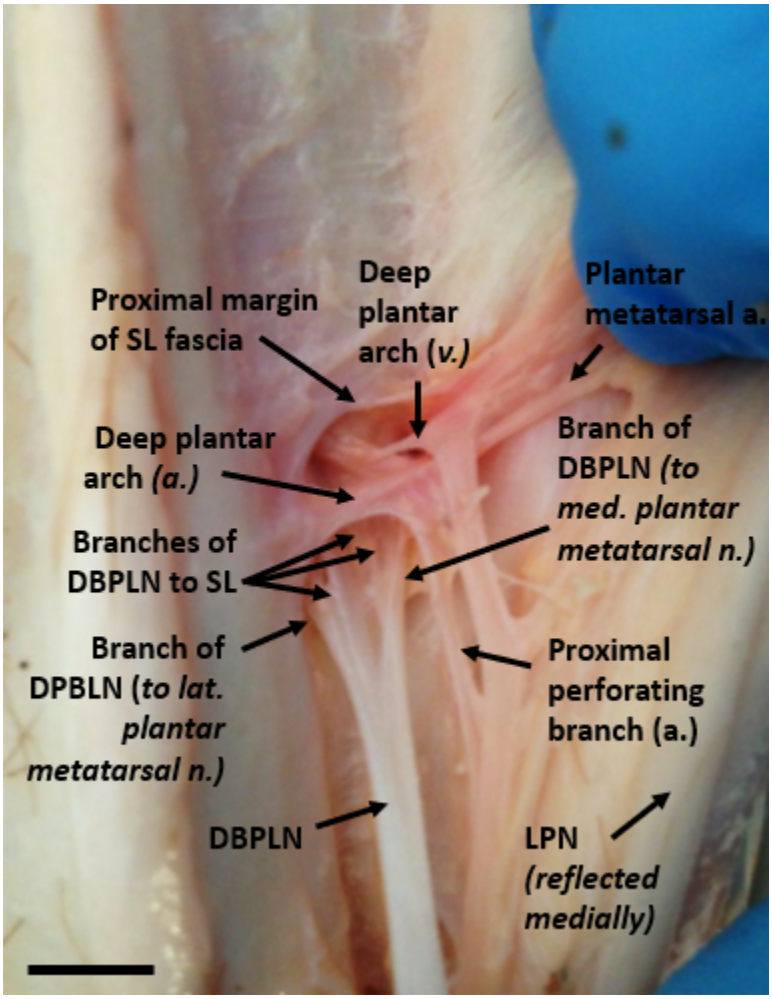
Figure 4

Example showing an additional branch from the lateral plantar nerve (LPN) coursing distal and superficial to the accessory ligament of the deep digital flexor tendon (ALDDFT) in the left hind limb. The main deep branch of the LPN (DBLPN) courses deep to the ALDDFT. This additional branch was absent in the contralateral limb. The limb is orientated as though the horse were in dorsal recumbency. Lateral is to the left and distal is to top of the image. a = artery, v = vein. Scale bar = 5mm. *This image has been reversed for comparative purposes.*

Figure 5

The accessory ligament of the deep digital flexor tendon (ALDDFT) in this example in the right hind limb covered the deep plantar arch and the proximal border of the deep metatarsal fascia as shown before (*a*) and after reflection of the ALDDFT (*b*). The position of the ALDDFT would make the approach to sectioning the deep metatarsal fascia difficult and increase the risk of iatrogenic damage to the deep plantar arch. The limb is orientated as though

the horse were in dorsal recumbency. Lateral is to the left and distal is to the top of the image. DBLPN = deep branch of the lateral plantar nerve, DDFT = deep digital flexor tendon, LPN = lateral plantar nerve, a = artery, v = vein. Scale bar = 5mm.



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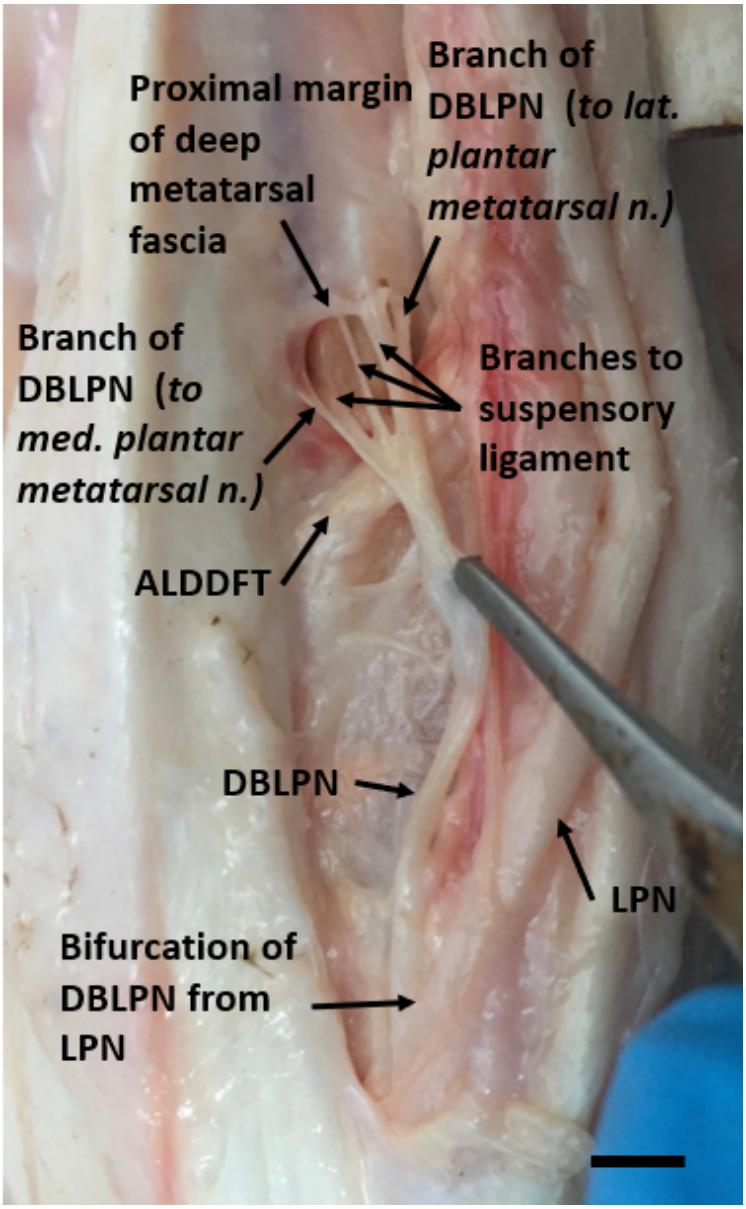
256x330mm (38 x 38 DPI)



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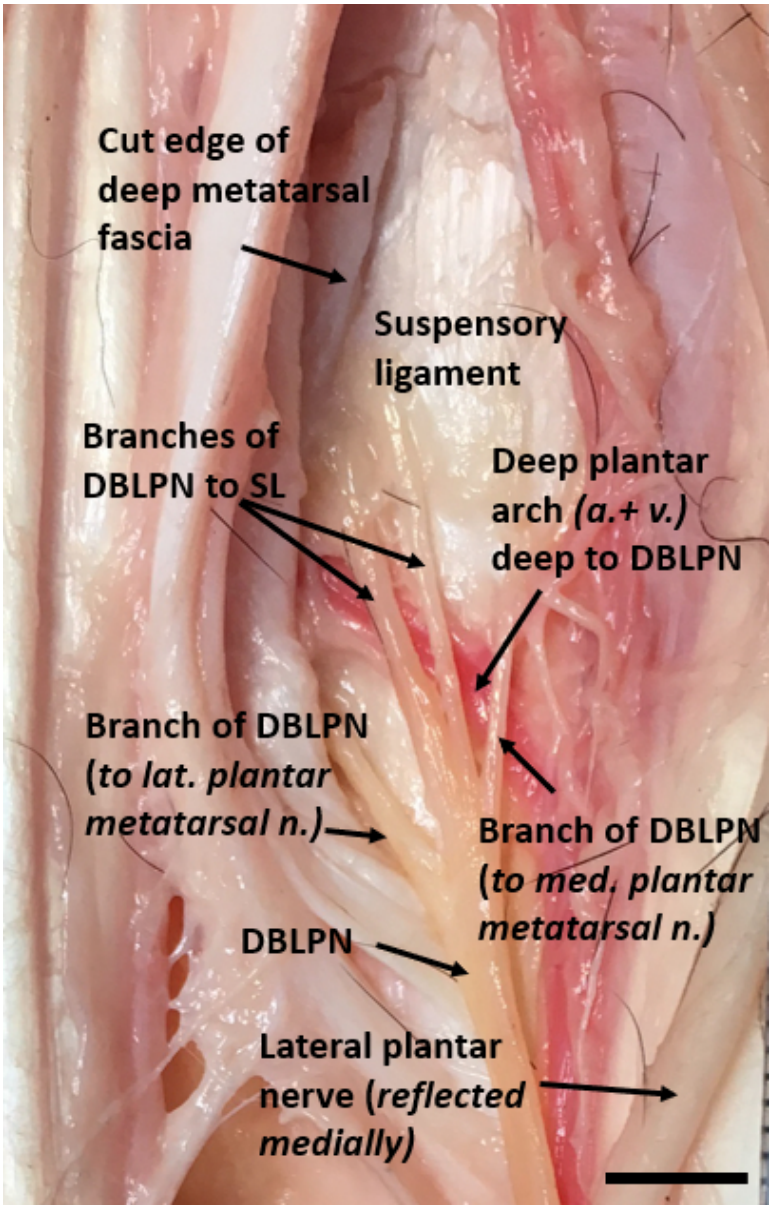
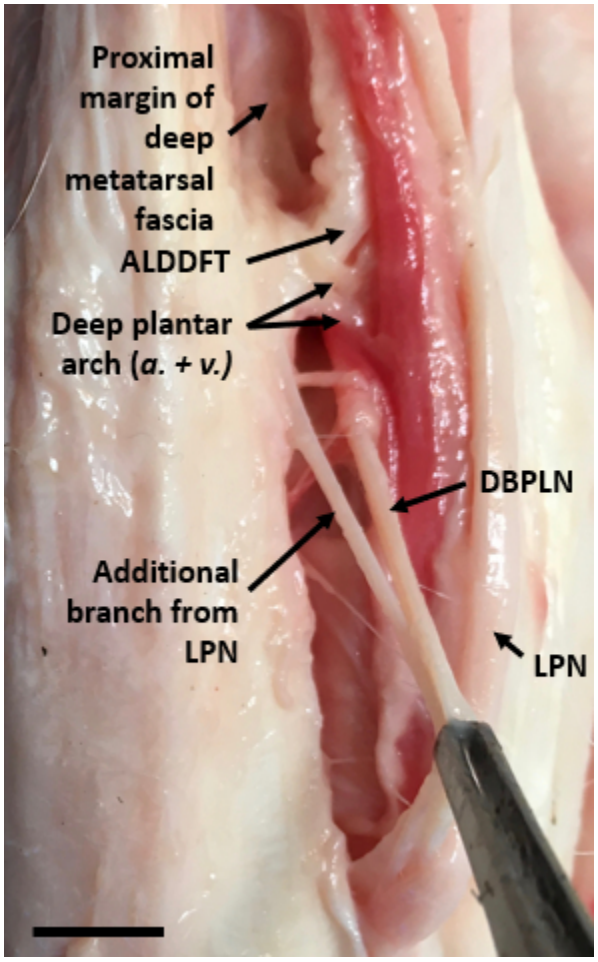


Figure 3
Example showing the deep branch of the lateral plantar nerve (DBLPN) and its branches superficial to the deep plantar arch in the right hind limb. The limb is orientated as though the horse were in dorsal recumbency. Lateral is to the left and distal is to the top of the image. a = artery, v = vein, SL = suspensory ligament, Scale bar = 5mm.



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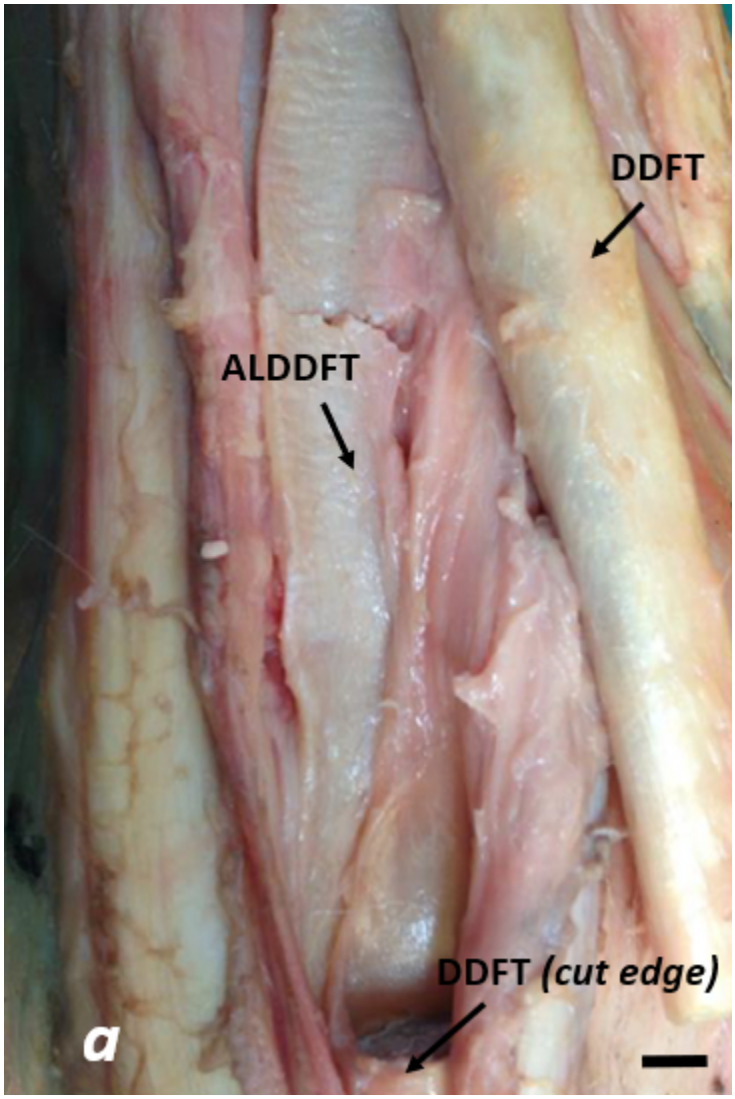
197x318mm (38 x 38 DPI)



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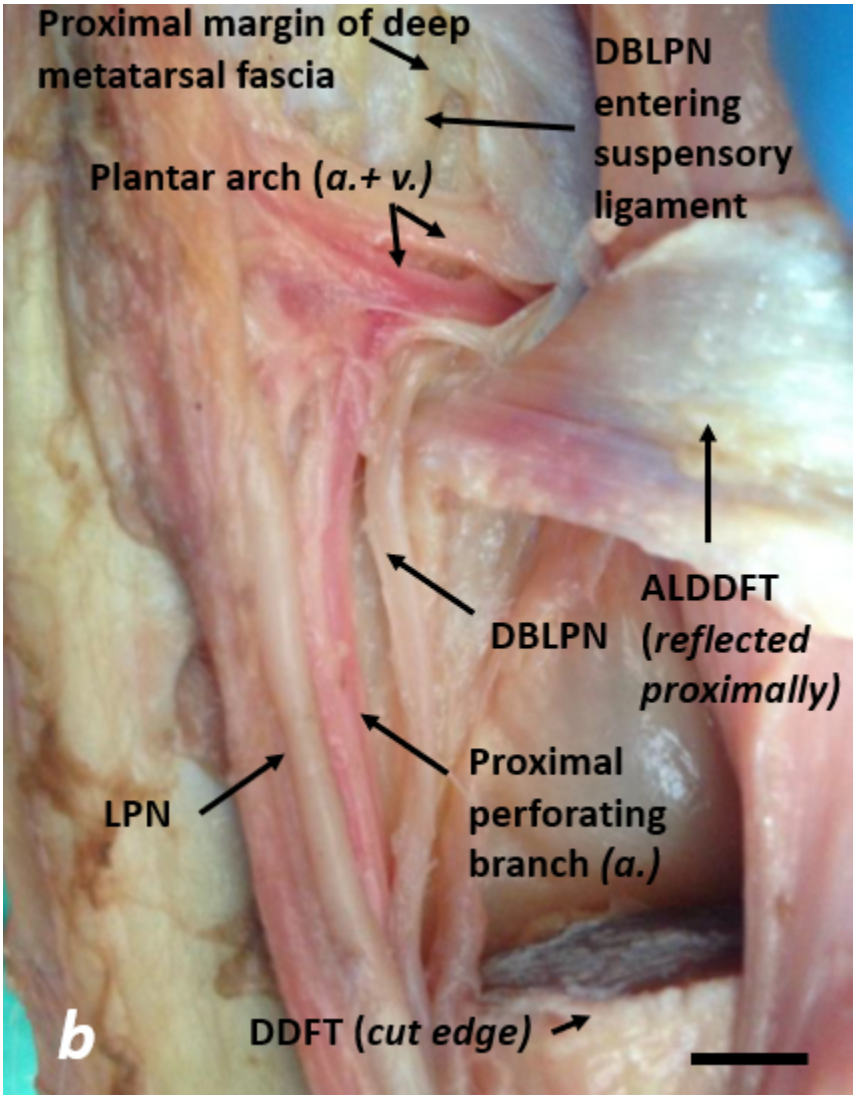
The accessory ligament of the deep digital flexor tendon (ALDDFT) in this example in the right hind limb covered the deep plantar arch and the proximal border of the deep metatarsal fascia as shown before (a) and after reflection of the ALDDFT (b). The position of the ALDDFT would make the approach to sectioning the deep metatarsal fascia difficult and increase the risk of iatrogenic damage to the deep plantar arch. The limb is orientated as though the horse were in dorsal recumbency. Lateral is to the left and distal is to the top of the image. DBLPN = deep branch of the lateral plantar nerve, DDFT = deep digital flexor tendon, LPN = lateral plantar nerve, a = artery, v = vein. Scale bar = 5mm.


Proximal margin of deep metatarsal fascia
DBLPN entering suspensory ligament
Plantar arch (a.+ v.)
ALDDFT (reflected proximally)
DBLPN
Proximal perforating branch (a.)
LPN
b
DDFT (cut edge)

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Enter a response in every cell, in column D. Blue, yellow and green shaded cells have lrestricted response options. Upload this checklist in ScholarOne. Choose file designation: EVJ manuscript checklist. Adjust row height if necessary but do not change column widths. Make sure the sheet remains in landscape layout			Grey cells below are for editors' use only
If you are submitting a review article, you do not need to complete the remainder of this checklist. Note in EVJ systematic reviews and metanalyses (and other forms of secondary research synthesis) are classified as general articles and as a minimum, the next question must be completed.			
1	If relevant, you may complete a checklist from recognised reporting guidelines (e.g. CONSORT, PRISMA, STROBE etc) instead of completing the remainder of this EVJ checklist. State which reporting guideline checklist you have uploaded		
If you are submitting an original article or technical note and have not uploaded a reporting guideline checklist, you must complete all of the remainder of this checklist			
Section 1: Title & Summary			
2	Confirm you have read and followed guidance on titles in our Author Guidelines (section 4.3)	confirmed	
3	Confirm you have read and followed guidance on optimising the summary for search engines in our Author Guidelines (section 4.11)	confirmed	
4	Confirm summary follows the structure described in our Author Guidelines	confirmed	
5	Confirm summary includes a concise statement of study design: see Author Guidelines 3.2 for guidance	confirmed	
6	Confirm there are data included in summary with point estimates and measure of precision. P values alone are not sufficient	confirmed	

7	Confirm P-values, where used, are presented to one significant figure (that is, the first non-zero number after the decimal place). The exceptions are P<0.001 and P>0.9, for very small and very large P values, respectively (apply in summary and remainder of manuscript)	confirmed	
Section 2: Main Manuscript			
8	The objectives of the research and any primary hypothesis/hypotheses must be stated.	*line nos. 70-74*	
9	Any secondary hypotheses should also be stated and hypotheses identified during the study must be reported	*NA*	
10	If a study aims to be exploratory (for example, where there are not just one or a few key *a priori* hypotheses), this must be stated.	*NA*	
11	Sample size must be transparently explained and discussed in every study where statistical inferences are made. If applicable, confirm that you have justified your use of a convenience sample (note we appreciate this is often unavoidable, particularly in retrospective clinical studies, but this must be stated transparently and will be regarded as a limitation which the EVJ editors will take into account when evaluating your paper, particularly where negative results are reported.)	*t include statistical comparisons or inferences*	
11a	Add line numbers to indicate where you have reported that you have used a convenience sample in methods, discussed this as a limitation and provided references to support your strategy.	*not applicable*	
12	For all analytical clinical and experimental studies, we strongly encourage you to include *a priori* sample size calculation(s). Assumptions on which this is based on should be stated and referenced if appropriate. For example, or a study comparing two interventions, this must include an estimate of the magnitude of difference between groups you expect to see, the sizes of type I and type II errors, and the mean and standard deviation of key outcome measures (based on pilot or published data), or where odds ratios are being examined, determine sample size based on a minimum of OR > or = 2.	*NA*	

13	The study subjects must be well described, providing all relevant information including their source, signalment and inclusion and exclusion criteria and the number of animals included in the study	*LIne nos. 77-78*	
14	For both prospective and retrospective clinical studies, you must Include a flow chart of subjects through each stage of eligibility, stating numbers agreeing to participate, randomisation, receiving the intervention in question, completing the study protocol and analysed for the study outcome	*NA*	
15	Where controls are used, their selection must be carefully described including, if appropriate, details of any matching criteria.	*NA*	
16	Describe any grouping or clustering in the sample (e.g. several horses from each of a number of stables, or repeated samples from individuals).	*NA*	
17	Explain methods of random selection or treatment allocation	*NA*	
18	Describe methods of measurement of variables or risk factors under investigation	*NA*	
19	Objectively and unambiguously define outcome measures	*Line nos86-92*	
20	Describe validation of measurement methods, use references if appropriate	*NA*	
21	Describe the use of operator masking and other methods to facilitate unbiased measurements	*NA*	
22	Confirm whether a “questionnaire” was used. This term should only be applied where a prescribed and formalised text or script has been used.	not applicable	
23	Questionnaire(s) must be provided as a supplementary item for online publication including, if necessary, an English translation with idenfifying details removed for double masked review.	not applicable	
24	Confirm whether informal follow-up used? This term refers to collection of information on clinical outcomes, for example, by unstructured telephone calls or emails with horse care-givers or referring veterinary surgeons,	not applicable	
25	The methods must explain how the content of informal follow-up	*NA*	
26	Clearly identify all statistical methods used.	*Line nos 93-94*	

27	Where more than one statistical method is used, state clearly which method is used for each comparison.	*NA*	
28	Confirm that you have names the software and version, including manufacturer (in brackets in text) used for statistical analysis	not applicable	
29	Describe methods used to test the extent to which data conform to the assumptions of normality	*NA*	
30	Describe key assumptionsunderpinning the analyses and evidence that these are sufficiently met (e.g. assumptions of equal variance etc.)	*NA*	
31	Justify one-tailed assumptions with reference to the hypotheses of the study	*NA*	
32	Describe how multiple comparisions were dealt with	*NA*	
33	Describe how clustering of data was ealt with	*NA*	
34	Where outcomes are measured on ordinal scales methods of analysis must be described. It is usually not appropriate to treat them as continuous variables.	*NA*	
35	Identify transformations (e.g. log transformation) that have been used, and provide evidence that the transformation achieved the desired effects.	*NA*	
36	Convert transformed results back into the original scale for reporting.	*NA*	
37	Identify and describe all variables available for inclusion in statistical model(s)	*NA*	
38	Describe how continuous variables were treated in the analysis	*NA*	
39	Describe whether (and if so, which) interaction terms were included	*NA*	
40	Describe how the final model(s) was determined	*NA*	
41	Describe the methods used to calculate test statistics (F test, likelihood ratio tests etc.)	*NA*	
42	Present a general description of the data prior to the results of statistical tests	*Line nos 86-93*	
43	Missing data must be identified, enumerated and explained	*NA*	
44	In longitudinal studies (cohort, interventions) baseline characteristics should be compared between groups	*NA*	

45	For data analysed using parametric methods , you must mean and standard deviation or confidence interval. Avoid standard error of the mean unless the goal is specifically to describe the precision of the estimate of the mean	*NA*	
46	For data analysed using non-parametric methods, you must present median and a central range, such as the interquartile range	*NA*	
47	Other results should be presented as point estimates (such as prevalence, mean difference, odds ratios etc.) with a measure of precision, preferrably 95% confidence intervals, ensuring the direction of any effect is clearly evident.	*NA*	
48	P-values can also be used but are not a substitute for confidence intervals.	*Line no. 94*	
49	P values must be used correctly, bearing in mind that p values simply define presence or absence of statistical signifiance, but do not imply importance. P values should always be accompanied by results to show differences between groups or comparisons	*Line no. 94*	
50	Confirm non-significant' findings are not described as 'trends'	not applicable	
51	Where Bayesian methods are used credible intervals should be presented.	*NA*	
52	In studies reporting the difference between groups, present confidence intervals for these differences rather than the confidence interval for each group	*NA*	
53	When percentages are contrasted, ensure it is clear whether absolute and relative differences are being used	*NA*	
54	Where sensitivity and specificity are estimated, confidence intervals must be included	*NA*	
55	Present univariable results using online supplementary material. Do not over interpret these	not applicable	
56	Multivariable models must be presented in a table and include number of observations , estimated coefficients, confidence intervals/standard errors of the coefficients, and where relevant odds ratios and P-values based on appropriate tests	*NA*	

57	Confirm results are presented to no more than one decimal place more than the original data; standard deviations or confidence intervals may need one additional decimal place (enter yes to confirm)	confirmed	
58	Confirm percentages presented to 1 decimal place or, for samples of less than 100, no decimal place (enter yes to confirm)	confirmed	
59	Confirm percentages are not used where there are less than 20 observations (enter yes to confirm)	confirmed	
60	'Non-significant' P-values do not indicate no effect. Confirm they are not interpreted in this way in the results or discussion (enter yes to confirm)	confirmed	
61	Statistical significance may be different to clinical importance; confirm this has been considered when results are discussed	not applicable	
62	Where multiple statistics tests are undertaken the potential implications in terms of the risk of type I errors should be discussed. Where appropriate, results should be described as exploratory rather than confirmatory	*NA*	
63	Statistical association does not provide direct evidence of causation. Where causation is of interest, other appropriate evidence should be presented in the discussion.	*NA*	
64	Discuss and robustly defend use of Critically Important Antimicrobials	*NA*	
65	Limitations of the study should be highlighted and results discussed in light of these. This may include, but is not limited to: selection and information biases; potential for residual confounding, impact of loss to follow-up and missing data; effects of deviation from the assumptions underpinning the analyses	*Line nos.165-167*	