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# Suspensory ligament size does not change after plantar fasciotomy and neurectomy of the deep branch of the lateral plantar nerve by ultrasonographic assessment

**Alexandra Scharf DVM, PhD | Cristobal Navas de Solis LV, MS, PhD | Sarah N. Sampson DVM, PhD | Kati Glass DVM | Ashlee E. Watts DVM, PhD**

Department of Large Animal Clinical Sciences, Texas A&M University, College Station, Texas, USA

**Correspondence**
Ashlee E. Watts, Department of Large Animal Clinical Sciences at Texas A&M University, College Station, TX, 77843, USA.
Email: awatts@cvm.tamu.edu

**Abstract**

**Objective:** To determine the short-term effect of plantar fasciotomy and neurectomy (PFN) of the deep branch of the lateral plantar nerve on the proximal suspensory ligament (PSL) cross-sectional area (CSA) in horses with hindlimb proximal suspensory desmopathy (PSD).

**Study design:** Analytical, observational, cohort study.

**Sample population:** Twenty-one horses.

**Methods:** Records of horses with chronic PSD treated by PFN were included if a preoperative ultrasonographic examination was available and at least one postoperative ultrasonographic examination. One masked observer measured the ultrasonographic cross-sectional area (CSA) of the PSL. Intraobserver reliability was determined by repeatedly measuring a subset of ultrasonographic images ($n = 127$). Two masked observers measured the cross-sectional area of the proximal suspensory ligament (PSL-CSA) on preoperative proton density (PD)-weighted transverse high field magnetic resonance images ($n = 19$ horses) . Agreements for PSL-CSA between preoperative ultrasonographic and MRI measures and between the two magnetic resonance imaging (MRI) observers were assessed. Follow up considered the horses' ability to return to exercise and their owners' satisfaction.

**Results:** The reliability of the ultrasonographic measurement of the PSL-CSA was excellent. Agreement between ultrasonographic assessment and MRI assessment of PSL-CSA was good. No difference was detected between preoperative (median, interquartile range; oblique-incidence, 2.07, 1.72-2.55; on-incidence, 2.23, 1.98-2.65) and postoperative (oblique-incidence, 2.08, 1.80-2.74; on-incidence, 2.28, 2.01-2.74) PSL-CSAs. At a median of 12 months (4-33 months), 16/20 (80%) owners reported the horse was "better" and 15/20 (75%) functioned at or above preoperative levels.

**Conclusion:** Ultrasonographic measurement of the PSL-CSA was reproducible and in good agreement with MRI measurement. The PSL-CSA was not influenced by PFN.

**Clinical significance:** The PSL-CSA cannot be used to guide return to function.

## 1 | INTRODUCTION

Proximal suspensory desmopathy (PSD), or injury of the proximal one-third of the suspensory ligament (PSL), is common in the hindlimbs of horses. For the diagnosis of hindlimb PSD, lameness is localized to the proximal metatarsus by diagnostic anesthesia, and imaging confirms ligament injury and/or bone injury at the PSL's enthesis.[1,2] In some instances, the lameness fails to improve with medical management, rest, and a controlled exercise program.[3] Failure to improve has been speculated to be related to a compartment syndrome.[4–7] Hindlimb plantar fasciotomy and neurectomy (PFN) of the deep branch of the lateral plantar nerve (DBLPN) has become a routine treatment for this compartment syndrome, and with careful case selection the outcome is good.[1,7–9]

Serial ultrasonographic examinations are often used during the management of PSD and a reduction of PSL size is one parameter that is used to indicate readiness for the advancement of the exercise level.[2,10] In horses treated surgically by PFN, the current literature describes return to athletic use approximately 2 months postoperatively, without serial ultrasonographic guidance.[1,7] Whether the PSL size by ultrasonographic assessment changes after a PFN in clinical patients is unknown. In the research setting, neurectomy of a single hindlimb DBLPN resulted in neurogenic atrophy of the muscle fibers within the PSL and a clear reduction of the cross-sectional area of the muscular part of the SL, histologically.[9] In the forelimb there was similar muscular atrophy after collagenase induced suspensory injury, which was followed by neurectomy of the deep branch of the lateral palmar nerve.[11]

Our objective was to compare the postoperative PSL cross-sectional area (CSA) with preoperative values after a PFN in horses determined to have chronic PSD by their clinical examination including diagnostic anesthesia and imaging. To evaluate the accuracy of our ultrasonographic cross-sectional area of the proximal suspensory ligament (PSL-CSA) assessments, we compared preoperative PSL-CSA values determined by ultrasound and high-field magnetic resonance imaging (MRI). We also assessed the intraobserver repeatability of ultrasonographic measurements of the PSL-CSA. Although our study is retrospective, all CSA measurements were made by masked observers at the time of data analysis and manuscript preparation. We hypothesized that the CSA of the PSL would be different up to 6 months after a PFN procedure, as measured ultrasonographically. We also hypothesized that there would be good agreement between ultrasonographic and MRI assessments of the PSL-CSA and that ultrasonographic measurements of the PSL-CSA would have good intraobserver repeatability.

## 2 | MATERIALS AND METHODS

We searched the medical records of our hospital from 2016 to 2019 to identify horses that underwent a hindlimb PFN for the treatment of PSD and had a preoperative ultrasonographic examination by CN and at least one postoperative ultrasonographic examination by CN for routine postoperative monitoring within 6 months of surgery. This inclusion criterion resulted in all horses having lameness that had been localized to the proximal metatarsus/distal tarsus by diagnostic analgesia and pathology of the PSL and/or its enthesis confirmed on high-field MRI and ultrasonographic examination ($n = 19$ horses) or ultrasonographic examination alone ($n = 2$ horses). In general, qualitative ultrasonographic assessment of PSL size, shape, fat/muscle orientation, fiber pattern and/or echogenicity as well as the adjacent bony margins was used to confirm a PSD diagnosis prior to recommending high-field MRI for more thorough evaluation of the PSL and tarsus. The PSL-CSA was never recorded in the imaging reports. Assessments for MRI examinations were also made by qualitative assessment of PSL size, shape, margins, fat/muscle orientation/size/shape, distinction between the fat/muscle bundles and surrounding collagenous tissue, collagenous tissue intensity on proton density (PD)-weighted, T2-weighted and short tau inversion recovery (STIR) sequences as well as contour and signal intensity of the enthesis, endosteal surface, and medullary cavity of the proximal metatarsus. All horses had chronic PSD, as the surgeons involved in this study do not recommend PFN in horses considered to have acute desmopathy. Postoperatively, all horses were prescribed our routine post-PFN controlled exercise program (Table 1).

Signalment data (age, sex, breed, discipline) and preoperative clinical assessment, including diagnostic anesthesia and imaging results, and whether the right or left hindlimb was the only or the predominant/primary lameness upon initial evaluation when there was bilateral hindlimb lameness, was recorded from the medical record. Medical records from postoperative visits were assessed for changes in our standard postoperative exercise recommendations (yes/no) and the diagnosis of acute desompathy (yes/no).

## 2.1 | Follow up

Owner-reported follow-up information on exercise level (controlled exercise program, full work at preoperative level, or full work above preoperative level), owner satisfaction (as compared with the situation before surgery, was the horse better, worse, or the same), and adherence to the prescribed controlled exercise program (yes/no) were collected from the medical records when available. When it was not available, the owner was contacted by telephone to obtain follow-up information. The time from surgery to follow up was also recorded.

## 2.2 | Ultrasonographic images

Transverse images from the medical record image archiving system obtained at 16, 18, and 20 cm distal to the point of the hock (DPOH) from the oblique-incidence and on-incidence ultrasonographic examinations made with a plantaromedial probe location were marked with a 4.0 cm line to calibrate cross-sectional measurements after exportation and exported as .TIF files. After the date and patient-identifying information have been removed from the ultrasonographic images, a single blinded investigator (CN, the same person who performed the original ultrasonographic examinations) determined the PSL-CSA on images viewed in a random order using ImageJ software (NIH, Bethesda, Maryland). The time of all ultrasonographic examinations relative to the day of surgery was recorded and reported. Other than the ultrasonographic conclusion on preoperative examinations and identification of acute desmopathy on postoperative evaluations, data regarding the machine, settings, use of a standoff pad, or measurements were not collected or used for analysis.

To determine intraobserver repeatability of the measurement of the PSL-CSA, CN measured the PSL-CSA in a subset of images (one image per limb per time point, $n = 127$) 2 more times, each in a different random order.

Two hospital-based ultrasound systems were utilized to perform the studies included in this report: Esoate MyLab 70 (Esaote North America, Inc. 11907 Exit Five Parkway Fishers, IN 46037) with a linear multifrequency transducer (5.5-12.5 MHz) (LA 523 transducer, Esaote North America, Inc.) and Vivid E9 (GE Healthcare, 500 West Monroe Street, Floor 21, Chicago, IL 60661) using a linear multifrequency transducer (5-13 MHz) (GE 12 L transducer, GE Healthcare). Most ultrasonographic images were obtained without a standoff pad, and the settings were optimized to the individual patient. Although preparation could not be confirmed in the medical record, in general, the limb was prepared by clipping, washing with soap and water, and drying prior to image acquisition. The ultrasonographer of this report routinely obtains and records on-incidence images with the limb weight-bearing and oblique-incidence images with the limb non-weight bearing and thus, these were the images used for analysis. In general, for oblique-incidence imaging, a foot stand was used, with the foot resting approximately 6 inches off the ground.

**TABLE 1** Controlled exercise program following a plantar fasciotomy and neurectomy for the treatment of hindlimb proximal suspensory desmopathy

| Postoperative time | Exercise level |
|---|---|
| 0-2 weeks | Stall rest |
| 2-4 weeks | Hand walk 20 min |
| 4-6 weeks | Ridden walk 20 min |
| 6-8 weeks | Ridden walk 10 min and ridden trot 10 min |
| 8-12 weeks | Ridden walk, trot and canter as appropriate for fitness |
| 12 weeks | Resume full work |

## 2.3 | Magnetic resonance images

When available, preoperative transverse PD-weighted MRI images (Siemens 3.0T Magnetom Verio MRI system, Siemens Medical Solutions USA, Inc., Malvern, Pennsylvania, with a large 4-channel flex coil) obtained at approximately 16, 18, and 20 cm distal to the point of the hock (DPOH) were retrieved from the medical record image archiving system, marked with a 4.0 cm line, and exported as .TIF files. The exported image location was 2, 4, and 6 cm distal to the tarsometatarsal joint, which we expect is approximately 16, 18, and 20 cm DPOH. Image order was randomized using a random number generator (Microsoft Excel) and patient identification and examination date were removed for masked PSL-CSA assessment. Using the 4.0 cm line to calibrate measurements, the PSL-CSA in each MR image was determined by 2 blinded observers (SS, KG), in the ImageJ software (NIH, Bethesda, Maryland). The time of MR examination relative to the day of surgery was recorded and reported. Other than the MRI report conclusions, data regarding the machine, settings, or clinical assessments were not collected or used for analysis.

## 2.4 | Statistical analysis

Signalment data, clinical work up, diagnoses and follow up were reported.

Ultrasonographic measurements of PSL-CSA obtained at 16, 18, and 20 cm DPOH were averaged for each limb and time point to yield a single PSL-CSA measurement for each limb at each time point. Preoperative MRI-based measurements of PSL-CSA obtained at 16,18, and 20 cm DPOH were also averaged for both observers yielding 2 PSL-CSA measurement for each limb (1 each for both investigators). Follow-up ultrasonographic evaluations were grouped for analysis at 2-4 weeks (T1), 6-10 weeks (T2), 3-4 months (T3), and 5-6 months (T4) postoperatively.

Data were log transformed for normality. Normal distribution was checked using the Shapiro-Wilk normality test, and then data were analyzed using a commercially available statistics program (Prism 8.0). Data from each limb were treated as individual cases. A mixed model repeated measure one way ANOVA was used to assess for differences in PSL-CSA following PFN for oblique-incidence measurements and for on-incidence measurements, with the repeated measures as times of evaluation within each limb. Each postoperative time point was compared to the preoperative value for each limb. When differences were present, follow-up testing was performed with Dunnett's multiple comparisons test. Differences were considered significant when the $P$ value was $< .05$. Nontransformed data are presented in figures.

To determine the intraobserver repeatability of ultrasonographic assessment of the PSL-CSA, we calculated intraclass correlation coefficient (ICC) estimates and their 95% confidence intervals using MedCalc software (MedCalc Software Ltd, Ostend, Belgium). The ICC calculations were based on a single measurement, absolute agreement, 2-way mixed-effects model. Values of less than 0.5 were considered to have poor reliability; values between 0.5 and 0.75 were considered moderately reliable; values between 0.75 and 0.9 were considered to have good reliability, and values greater than 0.9 were considered to have excellent reliability.[12,13] In a post hoc analysis, intraobserver repeatability of ultrasonographic PSL-CSA measurements was assessed using agreement indices that were calculated as previously described by Zauscher et al. The 95% limits of agreement were compared with the previously published target value of 30 $mm^2$ for PSL-CSA, which is used to show the ability to detect a clinically relevant change.[14]

To assess interobserver reliability on MRI measurements we determined intraclass correlation coefficient (ICC) estimates and their 95% confidence intervals using MedCalc software. The ICC calculations were based on a 2-way mixed effects model with a mean of raters for consistency. Values of less than 0.5 were considered to have poor reliability; values between 0.5 and 0.75 were considered moderately reliable; values between 0.75 and 0.9 were considered to have good reliability, and values greater than 0.9 were considered to have excellent reliability.

To assess for agreement between the MRI and ultrasonographic measurements we averaged the observations for each observer of MRI. We then made Bland-Altman plots for multiple observations per individual, to allow a graphical display of the mean difference between the ultrasonographic and MRI observations (bias) with 95% limits of agreement.

# 3 | RESULTS

## 3.1 | Medical record – signalment and preoperative clinical assessment

Twenty-one horses met the inclusion criterion of having received a PFN with a preoperative ultrasonographic examination and at least one postoperative ultrasonographic examination for routine monitoring. Horse breeds were predominantly Warmbloods (15), with 1 American Paint, 2 Quarter Horses, 1 Thoroughbred, 1 large pony breed, and 1 Connemara/Thoroughbred cross. There were 5 mares, 13 geldings, and 3 stallions, aged 6-18 years (median 10 years). Disciplines included dressage (10), eventing (5), hunter (2), jumper (1), reining (1), and western show (2). All horses had bilateral PFN for bilateral hindlimb lameness, with the primary lameness on the right hindlimb in 11 horses and the left hindlimb in 10 horses; ie, 11 horses had a right hindlimb lameness prior to diagnostic anesthesia and 10 horses had a left hindlimb lameness prior to diagnostic anesthesia. The lameness was localized to the proximal metatarsus/distal tarsal region by anesthesia of the DBLPN in all primary limbs. Prior to the DBLPN block, distal anesthesia to rule out the distal limb was performed in 18/21 primary limbs. The contralateral lameness became apparent after blocking out the primary limb in all horses and was resolved after DBLPN anesthesia in 12 limbs (Table 2). Eight secondary limbs did not undergo diagnostic anesthesia and diagnostic imaging was used to confirm bilateral PSD. Results of ultrasonographic and MRI examination of the PSL ranged from no significant findings to severe lesions (Table 2).

## 3.2 | Follow up

One horse was lost to follow up as the owners could not be contacted after the postoperative ultrasonographic examination 2 weeks from surgery. The median time for follow up was 12 months, ranging from 4 to 33 months (Table 3). Sixteen of 20 (80%) owners reported that their horse was "better," 2/20 owners reported "worse or the same," and 2/20 owners described the outcome as "other." Of the 16 that were reported to be "better," 15/20 (75%) were in full work and competing at the same level or higher, whereas 1 was still in a controlled exercise program at walk, trot, and canter under saddle. The 15 owners who reported their horses had returned to full work also reported that "yes" they adhered to the prescribed postoperative controlled exercise program, and full work commencing at 3 months after surgery. The 1 owner who reported only returning to walk, trot, and

**TABLE 2** Preoperative data from the medical records of horses that received a plantar fasciotomy and neurectomy of the deep branch of the lateral plantar nerve (DBLPN) for the treatment of hindlimb proximal suspensory desmopathy and the timepoints for postoperative ultrasonographic examinations [T1 (2-4 weeks), T2 (6-10 weeks), T3 (3-4 months) and T4 (5-6 months)] where 1 = examination and 0 = no examination at that timepoint

| Horse | Secondary limb diagnostic anesthesia | Left hindlimb ultrasound | Right hindlimb ultrasound | Left hindlimb MRI | Right hindlimb MRI | T1 | T2 | T3 | T4 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | DBLPN | | Mild | Minimal | Mild | 1 | 1 | 0 | 0 |
| 2 | None | Severe | Severe | Severe | Moderate | 1 | 0 | 0 | 0 |
| 3 | None | Mild | Mild | Minimal | np | 0 | 0 | 1 | 0 |
| 4 | DBLPN | Mild | Mild | Mild–moderate | Moderate | 1 | 0 | 1 | 0 |
| 5 | None | Mild | Mild | Mild | Mild | 1 | 0 | 0 | 0 |
| 6 | DBLPN | Moderate | Mild | Moderate | Moderate | 1 | 1 | 0 | 0 |
| 7 | DBLPN | Minimal | Mild | | | 1 | 1 | 1 | 1 |
| 8 | None | Mild | Mild | Mild | Mild | 0 | 1 | 1 | 1 |
| 9 | None | Mild | Mild | Mild | Mild | 0 | 0 | 0 | 1 |
| 10 | DBLPN | Mild | Mild | Mild | Mild | 0 | 1 | 1 | 1 |
| 11 | None | Mild | Mild | Minimal | Mild | 0 | 0 | 1 | 0 |
| 12 | DBLPN | Mild | Minimal | Mild | Mild | 1 | 0 | 0 | 0 |
| 13 | DBLPN | Mild | Mild | | | 0 | 0 | 1 | 0 |
| 14 | DBLPN | Moderate | Mild | Mild–Moderate | Mild | 1 | 1 | 1 | 0 |
| 15 | DBLPN | Mild | Mild | Mild–Moderate | Mild–Moderate | 1 | 0 | 1 | 0 |
| 16 | DBLPN | Mild | Mild | Mild–Moderate | Mild | 1 | 1 | 0 | 1 |
| 17 | DBLPN | no abn | no abn | Moderate | Mild | 1 | 0 | 0 | 0 |
| 18 | None | Mild | Moderate | Mild | Moderate | 1 | 0 | 0 | 0 |
| 19 | None | Mild | Moderate | Mild | Moderate | 1 | 1 | 0 | 1 |
| 20 | DBLPN | Mild–moderate | No abn | Mild–moderate | Mild | 1 | 1 | 0 | 0 |
| 21 | None | Moderate | Mild | Severe | Moderate | 1 | 1 | 1 | 1 |

**TABLE 3** Follow-up data for horses that received plantar fasciotomy and neurectomy

| Case | Follow-up months | Owner assessment | Exercise level at follow up | Adhered to exercise program | Miscellaneous |
|---|---|---|---|---|---|
| 1 | 13 | Better | Full, at | Yes | |
| 2 | 4 | Better | Controlled | Yes | |
| 3 | 17 | Better | Full, at | Yes | |
| 4 | 5 | Better | Full, at | Yes | |
| 5 | 4 | Other | N/A | No | Euthanized unrelated |
| 6 | 11 | Better | Full, at | Yes | |
| 7 | 34 | Better | Full, above | Yes | |
| 8 | 24 | Better | Full, at | Yes | |
| 9 | 7 | Better | Full, at | Yes | |
| 10 | 5 | Worse/same | N/A | Yes | Hock lameness |
| 11 | 13 | Better | Full, above | Yes | |
| 12 | 10 | Better | Full, at | Yes | |
| 13 | 4 | Other | N/A | No | Retired due to forelimb lameness |
| 14 | 9 | Worse/same | N/A | Yes | Hock lameness |
| 15 | 29 | Better | Full, at | Yes | |
| 16 | N/A | N/A | | | Lost to follow up |
| 17 | 22 | Better | Full, at | Yes | |
| 18 | 16 | Better | Full, at | Yes | |
| 19 | 32 | Better | Full, at | Yes | |
| 20 | 25 | Better | Full, at | Yes | |
| 21 | 8 | Better | Full, at | Yes | |

*Note*: Owners were asked if the horses' lameness was better, worse, or the same as compared with preinjury. Owners were asked what level of work their horse was in: full work or controlled exercise program. Owners were also asked if they had adhered to the prescribed exercise program.

canter under saddle did so as he intended to keep the horse only in flat work, irrespective of clinical improvement and he replied "yes" he had otherwise adhered to the prescribed protocol. Two of 20 owners (10%) reported that their horses' lameness was the "same or worse." Both of these horses had successfully returned to full work at the preinjury level after completing the prescribed controlled exercise program but subsequently became lame, and the lameness was again localized to the hock region. For the 2/20 horses (10%) classified as "other": 1 was euthanized for an unrelated problem, and 1 was retired due to continued forelimb lameness and both owners replied "no," as neither of these horses adhered to the prescribed exercise program.

## 3.3 | Ultrasonographic examinations

All horses had a preoperative ultrasonographic examination (to meet inclusion criteria) of both hindlimbs ($n = 42$ limbs) a median of 4 days prior to surgery, interquartile range (IQR) of 1 to 14 days, and at least one postoperative ultrasonographic examination to meet inclusion criteria (Table 2; Figures 1 and 2). None of the horses was diagnosed with acute desmopathy at any of the postoperative examinations and no owner was instructed to change the prescribed controlled exercise program. The PFN did not result in a change in the PSL-CSA either in the on-incidence (Figure 3A; $P = .11$) or in the oblique-incidence (Figure 3B; $P = .18$) ultrasonographic measurements (Figure 4).

## 3.4 | Reliability of ultrasonographic measurements

Reliability of ultrasonographic measurements was assessed by repeatedly measuring 127 oblique-incidence images. The intraclass correlation coefficient (ICC) estimates based on a single measurement, absolute agreement, 2-way mixed-effects model was .9652 with a 95%

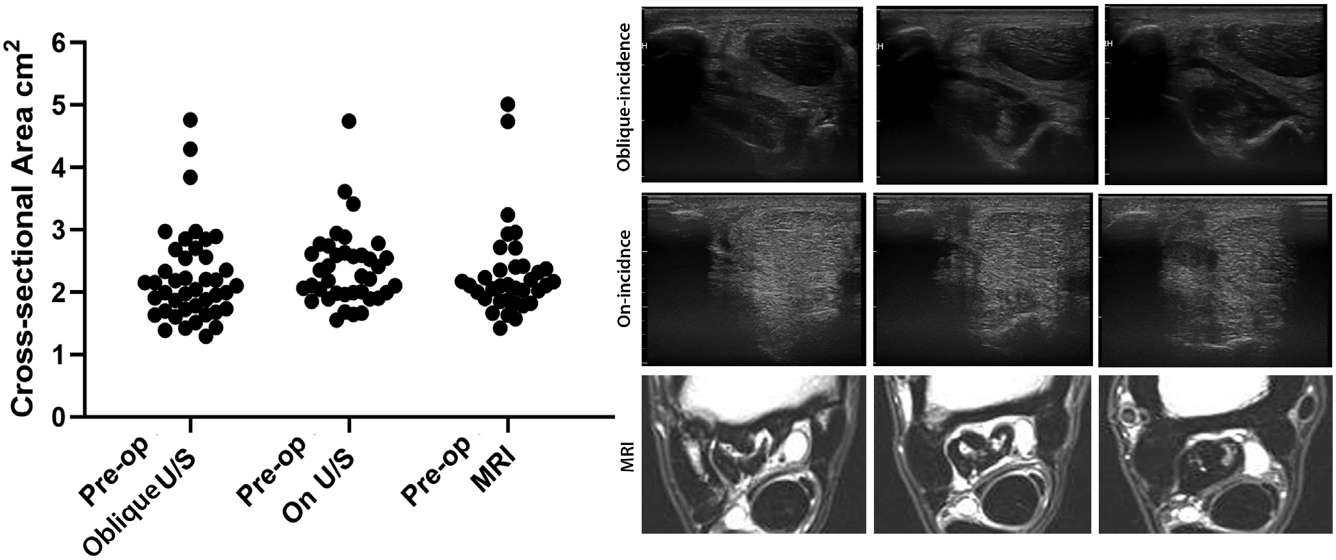


**FIGURE 1** Plots of the preoperative cross-sectional area of the proximal suspensory ligament by oblique- and on-incidence ultrasonographic assessment and MRI assessment. Corresponding example of preoperative oblique- and on-incidence ultrasonographic and MRI images from the limb with the primary lameness of horse 18 from 16, 18 and 20 cm distal to the point of the hock. The predominant findings for this limb were abnormal PSL size and shape and abnormal fat/muscle pattern, especially of the lateral bundle, in addition to shortened fiber pattern (not shown)

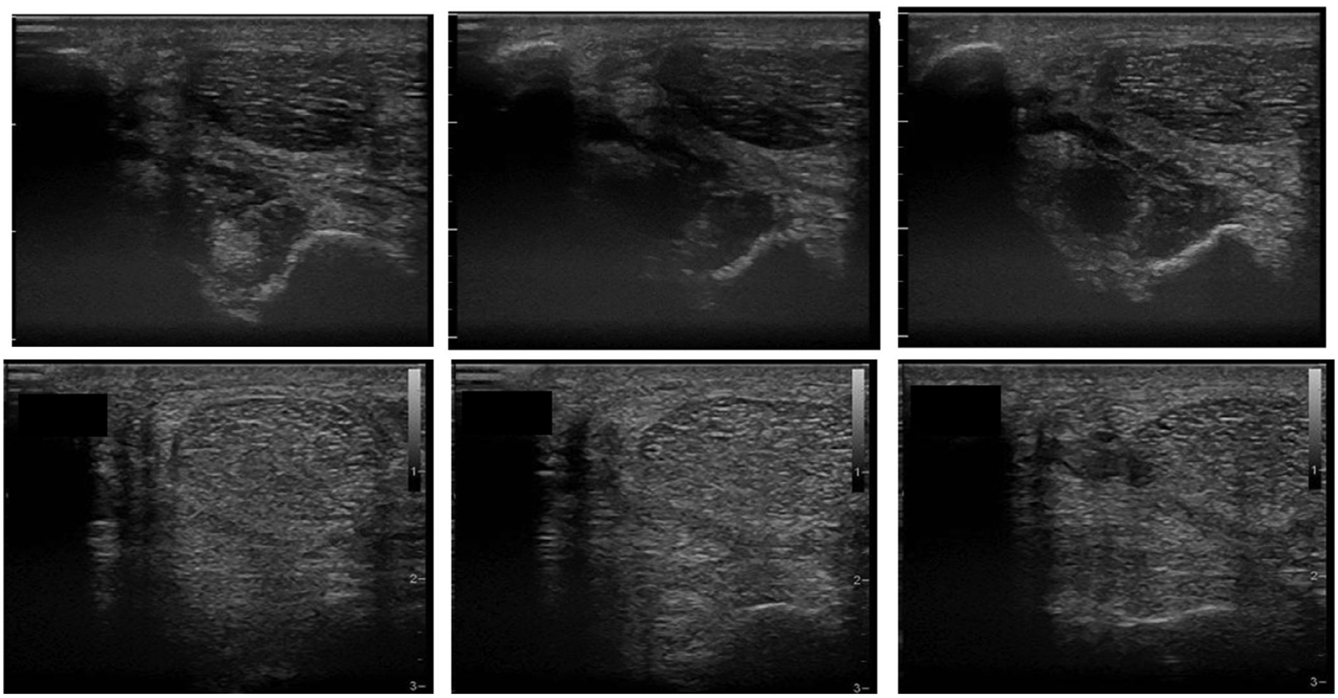

**FIGURE 2** Postoperative oblique- and on-incidence ultrasonographic from horse 18 at the second time point, 6-10 weeks

confidence interval of .9489 to .9764, indicating excellent reliability. The mean difference on the repeated measures was $-0.05$ cm$^2$ with a standard deviation of 0.178 cm$^2$ and the 95% confidence interval of limits of agreement were 0.30 to $-0.40$ cm$^2$. The intraobserver agreement indices as performed by Zauscher et al. were $0.95 \pm 0.05$, indicating excellent agreement. The repeated measures limits of agreement of 0.30 to $-0.40$ cm$^2$ were close to the

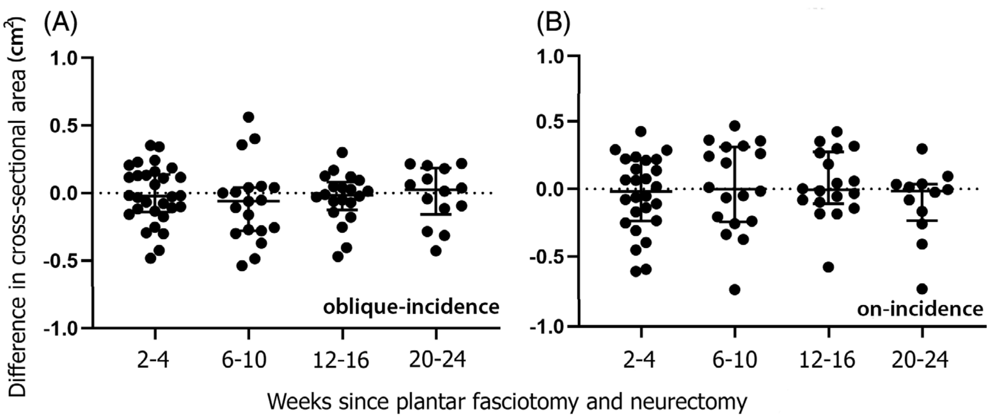


**FIGURE 3** Plots of the difference in cross-sectional area (cm$^2$) of the proximal suspensory ligament as measured by (A) oblique- and (B) on-incidence ultrasonographic assessment before and after surgery in 21 horses treated by plantar fasciotomy and neurectomy. Each dot represents the difference from the baseline measurement for each limb. A value of zero is no change from baseline. Bars indicate the median and interquartile range. Fifteen horses were examined at T1 (2-4 weeks postoperative), 10 horses were examined at T2 (6-10 weeks postoperative), 10 horses were examined at T3 (3-4 months postoperative) and 7 horses were examined at T4 (5-6 months postoperative). There were no statistical differences at any time point

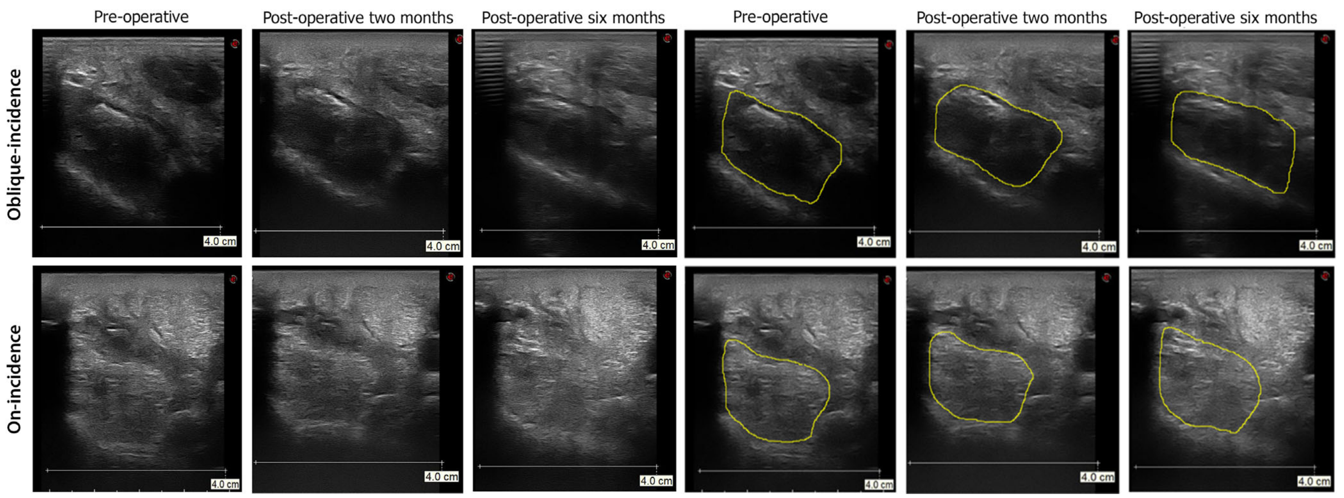


**FIGURE 4** Ultrasonographic images at 18 cm distal to the point of the hock from horse 21 before and after plantar fasciotomy and neurectomy without (left) and with (right) cross-sectional area tracing. The PSL-CSA values in cm$^2$ were 4.1, 3.9, and 3.8 cm$^2$ for oblique-incidence from left to right and 3.18, 3.38, and 3.15 cm$^2$ for on-incidence from left to right

reported target value of 0.30 cm$^2$ for PSL-CSA, which supports the ability of our study design to detect a clinically relevant change.[14,15]

### 3.5 | Reliability of MRI CSA measurements and agreement of MRI to ultrasonographic measurements

Nineteen horses had a preoperative MRI examination a median of 6 days prior to surgery (IQR of 2 to 17 days; Figure 1). Due to an error during image export, horse 21's MRI was not included for PSL-CSA analysis. The intraclass correlation coefficient (ICC) estimates of MRI measurements based on a 2-way mixed-effects model with a mean of raters for consistency was 0.9884 and their 95% confidence intervals were 0.9771 to 0.9942, indicating excellent reliability of our two observers.

Bland-Altman plots for agreement between the MRI and oblique-incidence ultrasonographic measurements for the mean difference between the two observations yielded 0.16 cm$^2$ (bias) with 95% limits of agreement of −0.32 to 0.64 cm$^2$ (Figure 5A). Bland-Altman plots depicting the mean difference between the MRI and on-incidence ultrasonographic measurements of the CSA showed −0.03 cm$^2$ (bias) with 95% limits of agreement of −0.71 to 0.78 cm$^2$ (Figure 5B).

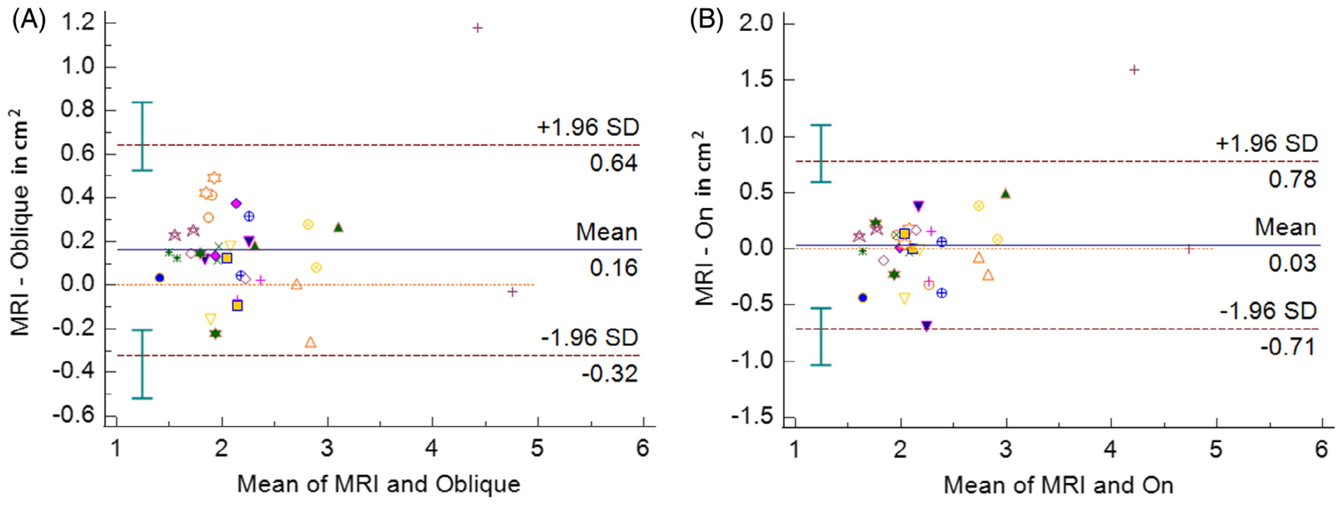


FIGURE 5 Bland-Altman plots for the agreement of MRI assessment and (A) oblique-incidence ultrasonographic assessment and (B) on-incidence ultrasonographic assessment of the proximal suspensory ligament cross-sectional area in $cm^2$ for the 18 horses with an MRI examination

## 4 | DISCUSSION

The horses received bilateral plantar fasciotomy and neurectomy (PFN) as treatments for PSD. A standard, postoperative controlled exercise program was prescribed, which included return to full work 3 months from surgery. We found no difference in the ultrasonographic measurement of PSL-CSA obtained preoperatively and 2 weeks to 6 months postoperatively. Consistent with previous reported outcomes after a PFN, owner follow up indicated that 15/20 (75%) of horses were "better" and in full work at a median of 12 months from surgery.[1,7–9] Our study suggests that PFN can return horses afflicted with PSD to full work without altering the PSL-CSA as measured ultrasonographically.

Although previous reports suggest that the plantaromedial window we used is appropriate for assessing the hindlimb PSL-CSA, we determined the reproducibility of our ultrasonographic assessment of the PSA-CSA to support our study methods.[16] The excellent intraclass correlation coefficients and agreement indices demonstrate adequate performance of ultrasonographic assessment of the PSL-CSA in this population of horses.[14,17] To further demonstrate the validity of our methods, we compared the ultrasonographic measures of PSL-CSA with measurements made by high-field MRI, when they were available. We found good agreement between ultrasonographic and MRI assessment, with a clinically acceptable mean bias that was an improvement over previously reported findings.[18] Despite the validity of ultrasonographic assessment of the PSL-CSA, we believe that repeated high-field MRI would be the ultimate test to compare preoperative and postoperative PSL-CSA.[19]

Prior to our study, we were unaware of reports on PSL-CSA after a PFN in horses with naturally occurring PSD; however, research reports suggested the PSL-CSA would change after PFN.[9,11] The lack of differences in PSL-CSA after PFN in horses with naturally occurring PSD could be due to the associated muscular pathology associated with chronic PSD or it may occur because of the inability of our ultrasonographic methods to detect muscle atrophy.[20] An alternative consideration might be that the PSL expands immediately after the release of restricting plantar fascia and then diminishes in size resulting in a CSA not different from that measured preoperatively.

A possible limitation of our study is the short-term nature of postoperative ultrasonographic examinations, with examinations extending no further than 6 months postoperatively. Further, not all limbs were examined at all time points and only 14 limbs were evaluated at the latest, 5-6 month postoperative time point. To better understand the long-term effect of PFN on PSL-CSA, later time points should be studied and although we had a follow up of greater than 12 months on 10 horses, longer term follow up may be useful. However, in the context of monitoring the horse as it returns to full work, these early postoperative data are helpful as our report, and those of others, calls for return to full work by 3 months after surgery.[1,7,8] Another limitation that we noticed despite excellent intraclass correlation coefficients, agreement indices, and narrow limits of agreement, was that our blinded and randomized design could have limited the matching of PSL shape between sonograms (Figure 4). We think this design was needed to test the study hypothesis. Finally, it is also possible that our study was insufficiently powered to register an apparent small difference present between the preoperative and postoperative PSL-CSA measurements.

To control for some of the inherent limitations of retrospective studies, we performed masked and randomized ultrasonographic assessments of PSL-CSA. This approach enabled us to eliminate our inherent bias toward artificially registering a smaller PSL-CSA in measurements obtained post operatively. Indeed, our excellent intraobserver repeatability demonstrates that we were able to minimize subjectivity in our assessments.

In conclusion, there was no difference in ultrasonographic PSL-CSA measurements obtained 2 weeks to 6 months after performing PFN to treat hindlimb PSD, in comparison with results obtained preoperatively. However, 15 out of 20 horses with follow up were able to return or exceed their level of performance. This finding should encourage clinicians monitoring horses that appear to be responding well to PFN, without an apparent decrease in the PSL-CSA, to stay the course with the postoperative controlled exercise regimen, as a change in the PSL CSA cannot be used to guide return to function.

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## CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

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## SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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