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Modified abaxial sesamoid nerve block provides enhanced proximal diffusion compared to basisesamoid block and lower proximal diffusion than traditional low plantar nerve block in equine hind limbs: ex vivo and in vivo study

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OBJECTIVE
To determine the proximal diffusion distance of radiopaque contrast medium and mepivacaine/methylene blue solution and incidence of inadvertent intrasynovial and intravascular injections of modified sesamoid nerve block (MASB) when compared with traditional plantar nerve analgesia techniques of the equine distal hind limb.

SAMPLE
Ex vivo model: 18 hind limbs; and in vivo model: 5 horses in a crossover study.

METHODS
In the ex vivo model, a mepivacaine/methylene blue solution was used to compare the diffusion distance between MASB, basisesamoid block (BSB), and traditional low plantar block (TLPB). Ten minutes after injection, skin was dissected and proximal diffusion distance of the dye patch was measured. In the in vivo model, both hind limbs were injected with radiopaque contrast medium with either MASB or TLPB. Ten minutes after injection, a radiograph was acquired and the proximal diffusion of the contrast medium patch was measured.

RESULTS
In the ex vivo model, solution proximal diffusion distance for MASB was significantly longer than BSB ($P < .050$) and significantly shorter than TLPB ($P < .050$). Both techniques reached the proximal aspect of DFTS similarly ($P = .289$), and no difference in the incidence of intrasynovial or intravascular injections was observed ($P = .292$). In the in vivo model, contrast medium proximal diffusion of MASB was significantly shorter than TLPB ($P < .050$). The proportion of injections that diffused subcutaneously to the proximal aspect of the proximal pouch of the DFTS was not significantly different between techniques ($P = .136$). No difference in the incidence of DFTS intrasynovial or intravascular injections was observed ($P = .305$).

CLINICAL RELEVANCE
MASB presented significantly more proximal diffusion than BSB and less proximal diffusion than TLPB, consistently reached the proximal aspect of DFTS, and presented a very low risk of intrasynovial and intravascular injections.

Keywords: perineural analgesia, contrast medium, diffusion, plantar nerve, equine

Despite advances in the diagnosis of equine musculoskeletal pathologies over the last decades, diagnostic analgesia is still an important component of the orthopedic examination in the horse.[1,2] Two major disadvantages of the use of perineural anesthesia are the undesired proximal diffusion of the local anesthetic[3–7] and the risk of inadvertent intrasynovial and intravascular injections.[5,6,8,9] Intrasynovial injections or proximal diffusion of local anesthetic can potentially lead to desensitization of structures other than intended. Failure of desensitization can occur when the anesthetic is injected intravascularly or not in the correct

location. Finally, inadvertent intrasynovial injections without proper aseptic preparation of the skin can increase the risk of synovial infections.

The plantar and plantar metatarsal nerves are the main contributors to the innervation of the distal hind limb and should be anesthetized when aiming at desensitizing this region. When blocking medial and lateral plantar and plantar metatarsal nerves, proximal to the fetlock region, it is commonly called a low 4-point block, and when including the desensitization of the dorsal metatarsal branches, it is known as a low 6-point block.[1,2] When performing the low 4- or low 6-point block, the plantar nerves are traditionally desensitized at an injection site slightly proximal to the button of the II and IV metatarsal bones and proximal to the digital flexor tendon sheath (DFTS), between the branch of the suspensory ligament (SL) and the deep digital flexor tendon (DDFT),[1,2] directing the needle toward the dorsal aspect of the DDFT.[2] In the present report, this injection site is referred to as the traditional low plantar block (TLPB). The plantar nerves can also be desensitized abaxial to the proximal sesamoid bones, and this technique is called abaxial sesamoid block (ASB).[1] A modification of the ASB, frequently used in the equine practice aiming at decreasing proximal diffusion, is to inject at the base and abaxial to the sesamoid bone, directing the needle distally. This modification is known as the basisesamoid block (BSB).[1,2] Due to the epidemiology of the pathologies in the hind limbs and increased risk for the operators, some clinicians prefer to start the regional anesthesia with the low 4- or low 6-point block to rule out a source of pain localized to the distal limb.[2] Interestingly, it has been previously demonstrated that the perineural anesthesia of the palmar metacarpal nerves shows very little proximal diffusion.[6] On the other hand, significant proximal diffusion has been observed when desensitizing the palmar nerves.[6] It is not clear whether the radiopaque contrast medium diffusion in the hind limbs behaves similarly than in the forelimbs.

When performing the TLPB in clinical cases, we have observed that the location of the proximal pouch of the DFTS might vary significantly depending on the effusion of the sheath[1] and/or position of the limb while performing the block (ie, while lifting the limb for performing the low 4 point, the reciprocal apparatus causes a semiflexion of the fetlock that displaces the DFTS proximally). These variations might force the clinician to perform the TLPB more proximally,[1] potentially increasing proximal diffusion of the local anesthetic and the risk of false-positive results. On the other hand, a significant risk of inadvertent intrasynovial injection of the DFTS (as high as 30%) has been reported when using the TLPB technique.[6,9] Modified or new perineural analgesia techniques should aim at decreasing the risk of false-positive results and inadvertent intrasynovial and intravascular injections.

To our knowledge there are no contrast studies of the plantar nerves in the hind limb. Our aim was to determine the diffusion pattern of the TLPB in the hind limbs and also try to demonstrate that a simple modification of the ASB technique (increased volume of injectate and proximal direction of the needle) could cause more proximal diffusion than with the BSB but less than with the TLPB. From a practical point of view, we believed that this modification would allow the clinician to desensitize the plantar nerves safely with less proximal diffusion when compared to the TLPB.

We hypothesized that when using a modification of the abaxial sesamoid nerve block (MASB), the radiopaque contrast medium diffusion would reach at least the proximal margin of the DFTS. It was also expected to have significantly more proximal diffusion of the contrast medium in the TLPB when compared to the MASB and a significantly more proximal diffusion of the MASB when compared to the BSB. Finally, we expected to demonstrate that the MASB is a safe technique with a low risk of intrasynovial and intravascular injections.

Methods

Procedures

Ex vivo model—Eighteen fresh hind limbs collected in a slaughterhouse were used for the ex vivo study. Mepivacaine stained with 0.1% methylene blue dye was injected using a 21-G X 25-mm needle. Four milliliters of solution was used for the MASB and 2.5 mL of solution was used for the BSB and the TLPB. The specimens were injected randomly, mimicking the flexion of the limb and emulating the elevation of the hind limb used when performing distal limb perineural analgesia. The aforementioned perineural techniques were randomly assigned to the lateral or medial plantar nerve of each hind limb. Eight limbs were used to compare the BSB with the MASB and 10 limbs to compare the MASB with the TLPB. Ten minutes after injection, the skin was dissected and the distance between the lateral aspect of the base of the sesamoid bone and the most proximal aspect of the dye patch was measured. The limbs were dissected, and the distance from the lateral aspect of the base of the sesamoid bones and the most proximal aspect of the proximal pouch of the DFTS was measured. Intrasynovial and intravascular injections were recorded.

In vivo model—Five sound crossbred adult horses were used for this study, including 4 mares and 1 gelding, weighing 275 to 400 kg and ranging in age between 6 and 22 years old, from the herd of the School of Veterinary Medicine, Universidad Nacional, Costa Rica. Horses underwent a clinical examination to rule out animals with significant distension of the DFTS and other orthopedic pathologies in the hind limbs.

The animal use was approved by the Animal Welfare Committee, School of Veterinary Medicine, Universidad Nacional, Costa Rica (approval No. FC-SA-CBAB-EMV-ACUE-002-2017).

A crossover methodology was selected for this study using 5 horses in 2 phases. During the first phase the lateral and medial plantar nerves of all the left hind limbs were injected using the MASB and the right hind limbs using the TLPB. In the second phase, at least 7 days apart, the blocks were repeated using

the MASB in the right hind limb and the TLPB in the left hind limb.

Before the injections, the animals were sedated and given 1.1 mg of xylazine/kg (Procin Equus) IV combined with 0.01 mg of butorphanol/kg (Butormin) or 0.1 mg of morphine/kg (Morfina Clohidrato). Injection sites were aseptically prepared using a 3-minute scrub with 4% chlorhexidine (DispoScrub) followed by a 70% alcohol wipe (Alcohol Etílico de Fricciones). With the horse in weight-bearing, the most proximal aspect of the proximal pouch of the DFTS was localized ultrasonographically and marked externally with a permanent marker. Thereafter, the distance between this point and the palpable lateral aspect of the base of the proximal sesamoid bone was measured. All the measurements were performed by the same board-certified specialist in veterinary surgery (RJE).

All injections were performed by the same board-certified specialist (RJE). The hind limbs were held off the ground by another operator, extending it backward and manually extending the metatarsophalangeal joint while the injections were performed. In the case of the MASB technique, a 21-G X 25-mm needle was inserted plantar to the neurovascular bundle and abaxial to the proximal sesamoid bone in a distoproximal direction. Four milliliters of the radiodense contrast medium (iohexol 64.7%) was injected SC. The procedure was performed in the medial and lateral plantar nerves. For the TLPB, the injections were performed between the branch of the SL and the DDFT, proximal to the distal aspect of the splint bone and 1 cm proximal to the observable margin of the proximal pouch of the DFTS. A 21-G X 25-mm needle was inserted perpendicular to the skin, and 2.5 mL of contrast medium was used for this block.

The injection sites were wiped with alcohol to remove any residues on the skin. The horses were not exercised or moved after the injections. Dorsoplantar radiographic projections were obtained 10 minutes after the injections using a direct digital radiography equipment (X-AQS; Examion). A metallic marker of a known length was placed at the panel and used for calibration. After calibration, the same operator (RJE) measured the length of all the contrast medium patches using the software of the aforementioned digital x-ray system. The procedure was not blinded since the difference between both techniques was very evident (different injection sites). For both techniques, the distances were measured from the lateral aspect of the base of the proximal sesamoid bone to the most proximal aspect of the contrast medium patch **(Figure 1)**.

Statistical analysis

For both models, diffusion was compared by an unpaired Student *t* test. For the in vivo model, the effect of factors like technique, phase, side, and corresponding interaction was evaluated using a general linear model design followed by a Tukey post hoc comparison, when appropriate.

The statistical assumptions of normality and homoscedasticity were evaluated by the Anderson-Darling and Levene tests. The 2-proportion test was also applied to determine statistical equivalence between techniques based on the compliance ratio (proportion of samples fulfilling diffusion distances) and incidence of intrasynovial and intravascular injections. A 95% confidence level and α = 0.05 were assumed for the analysis, and tests were performed using Minitab software (version 19.1.1; Minitab Inc). The DFTS intrasynovial injections were represented using descriptive statistics.

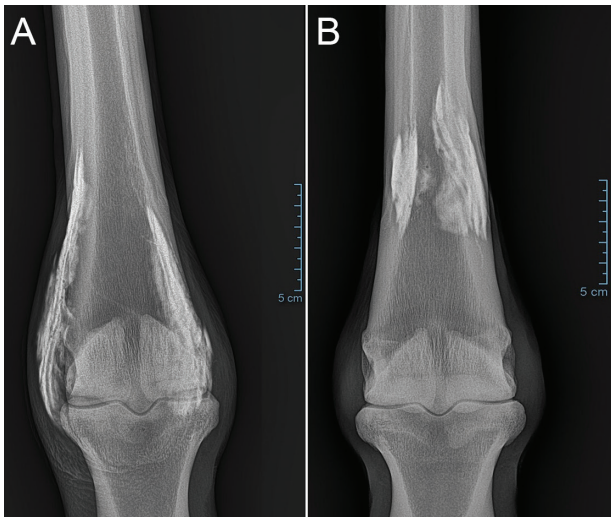

Figure 1—Comparison of (A) the modified abaxial sesamoid block (MASB) with (B) the traditional low plantar block (TLPB). Injections were performed lateral and medial using a different technique on each limb. The radiographic images were obtained 10 minutes after the injection. The proximal diffusion was measured from the abaxial aspect of the base of the sesamoid to the most proximal aspect of the contrast patch. Note the more proximal diffusion of the contrast medium of the TLPB (B) compared to the MASB (A).

Results

The data complied with the statistical assumptions of homoscedasticity (Levene test, $P > .050$) and normality (Anderson-Darling test, $P > .050$), validating the application of Student *t* and general linear model tests.

Ex vivo model—The proximal diffusion distance obtained by the MASB technique was significantly lower compared to the TLPB ($P < .050$). MASB distance was 72.0 ± 9.0 mm (95% CI, 65.1 to 78.9 mm), while TLPB reached 124.7 ± 11.5 mm (95% CI, 116.5 to 132.9 mm). No significant difference was found between techniques regarding expected proximal diffusion (reaching at least the proximal pouch of the DFTS; $P = .289$; difference, −0.11; 95% CI for difference, −0.32 to 0.09) nor for the incidence of intrasynovial and intravascular injections ($P = .292$; difference, 0.10; 95% CI for difference, −0.09 to 0.29). One MASB injection (1/10) was intravascular, while none were observed using the TLPB. Proximal diffusion was significantly less for the BSB (11.2 ± 5.2 mm; 95% CI, 6.8 to 15.5 mm) compared to the MASB (67.3 ± 8.5 mm; 95% CI, 60.2 to 74.3 mm; $P < .050$). No intrasynovial or intravascular injections occurred for either technique **(Figure 2)**.

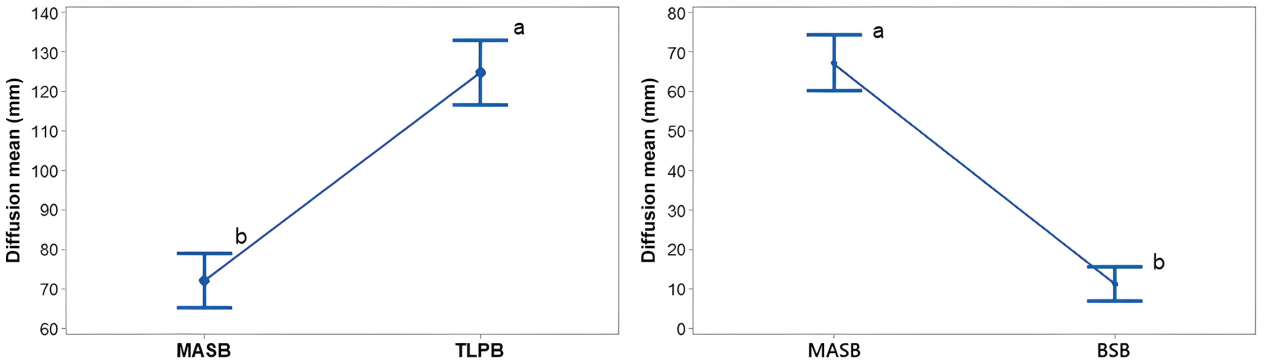

Figure 2—Summary of the statistical analysis for the ex vivo model. Graphs of the mean diffusion of the contrast medium between MASB and TLPB on the left and MASB and basisesamoid block on the right. The MASB showed significantly more proximal diffusion than the basisesamoid block and significantly less than the TLPB ($P < .050$; Minitab version 19.1.1; Minitab LLC).

In vivo model—The MASB technique presented a significantly lower proximal diffusion distance of the contrast medium patch when compared to the TLPB ($P < .050$). The mean (95% CI) for the MASB was 84.95 ± 14.66 mm (95% CI, 77.88 to 92.01 mm), while that of the TLPB was 134.90 ± 16.15 mm (95% CI, 127.34 to 142.46 mm). The in vivo study phase of the crossover model (first or second), injection side (medial or lateral plantar nerve), and multiple interactions between these factors did not significantly influence the variability of the results ($P = .777$). The test of 2 proportions indicated that the percentage of events that met the expected diffusion (reaching at least the proximal aspect of the proximal pouch of the DFTS) and the incidence of intrasynovial injections were not significantly different for either technique ($P = .136$; difference, −0.10; 95% CI for difference, −0.03 to 0.23; MASB, 2/20 vs TLPB, 0/20). Only 1 of 20 injections using the MASB were intrasynovial in the DFTS, while no intrasynovial injections were observed when using the TLPB ($P = .305$; difference, −0.05; 95% CI for difference, −0.15 to 0.05; MASB, 1/20 vs TLPB, 0/20; **Figure 3**). No intra-articular injections of the metatarsophalangeal joint were observed using either technique.

Discussion

The aim of this study was to determine whether the MASB presented more proximal diffusion than the BSB but less than the TLPB. This study demonstrated that, in the ex vivo model, MASB showed significantly more proximal diffusion than the BSB and significantly less than the TLPB. There was no significant difference between the proportion of injections reaching at least the proximal aspect of the DFTS when comparing the MASB with TLPB. No significant differences of intrasynovial and intravascular injections were observed between the techniques. In the in vivo model, the MASB presented significantly less proximal diffusion when

Technique	Compliance ratio	Phase	Side	Mean (mm)	StDev (mm)
MASB	90% (18/20)	01	lateral	85,40	12,46
			medial	78,25	19,09
		02	lateral	81,00	9,35
			medial	93,80	16,98
TLPB	100% (20/20)	01	lateral	138,80	17,24
			medial	131,80	4,92
		02	lateral	132,20	14,89
			medial	136,8	25,5

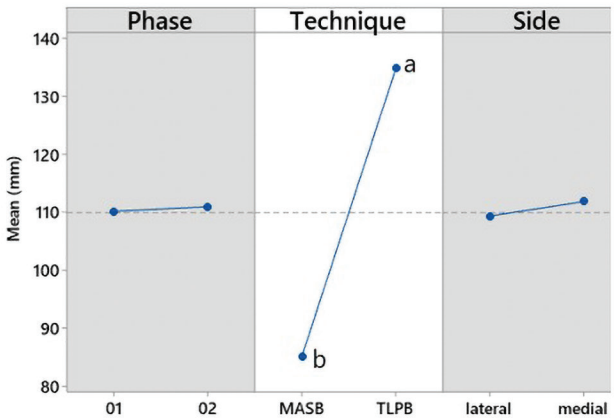

Figure 3—Summary of statistical analysis for the in vivo model. Differences between technique, phase, side, and their interactions were determined. The proximal contrast medium diffusion was significantly different between techniques. The other evaluated parameters were not significantly different ($P < .050$). The compliance ratio (reaching the proximal aspect of the DFTS) showed no significant difference between the MASB and TLPB (Minitab version 19.1.1; Minitab LLC).

compared to the TLPB 10 minutes after contrast medium injection. The phase of the crossover study, the injection side (lateral or medial plantar nerve), and other interactions between these factors did not significantly influence the variation of the results. The percentage of injections reaching at least the proximal aspect of the DFTS and the incidence of intrasynovial injections in the DFTS were not significantly different when comparing the MASB and TLPB. Our results suggest that the MASB is a safe and reliable technique with less proximal diffusion than the TLPB and a low risk of intravascular and intrasynovial injections.

It has been suggested that needle direction, volume of injected solutions, and limb position may affect proximal contrast medium diffusion.[6,9] Nagy et al[6] highlighted the importance of needle direction to avoid proximal diffusion of the injected solutions. Seabaugh et al[9] reported that injections to the palmar nerves with 4 mL of solution resulted in significantly greater diffusion compared to lower volumes. The use of 4 mL of contrast medium combined with longer needles (21 G X 25 mm) and proximal direction of the injection allowed us to consistently reach the proximal aspect of the DFTS but have significantly less proximal diffusion than the TLPB. Limb position has also been implicated as a variable involved in the diffusion of the injected solution. Seabaugh et al[9] suggested that non–weight-bearing position most likely favors proximal diffusion due to relaxation of the soft tissues. In our study, for safety reasons, all the blocks were performed with the hind limbs held off the ground by an operator. If this position has a positive effect on proximal diffusion, it may have affected both techniques similarly.

The risk of DFTS penetration using the TLPB techniques raises concerns about potential synovial infections.[6,9] Incidences of inadvertent DFTS intrasynovial penetrations as high as 30% have been previously reported when performing the low palmar nerve block.[6] Our study demonstrated that the MASB technique allows safe block of the plantar nerve with a very low risk of inadvertently penetrating synovial structures. No significant difference in the incidence of intrasynovial injections was observed when comparing MASB and TLPB. In the case of intrasynovial injections in the DFTS, 1 of 20 injections were intrasynovial when using the MASB, while none were within the DFTS when using the TLPB. No intra-articular injections of the metatarsophalangeal joint were observed using either technique. It is important to mention that in the case of DFTS penetration, the mare was fractious and started kicking once the needle was inserted. This movement probably displaced the needle proximally into the DFTS. Even though it seems not very likely to have this complication, it is important to take it into account while preparing the limb for this technique. Previous studies have used a fixed point to select the injection site for performing the low palmar nerve block,[6,9] and this probably did not allow modification of the technique for cases in which the DFTS was more distended. During this study, we observed an interesting correlation between the most proximal aspect of the DFTS observed ultrasonographically and a change in the angulation of the skin located at the lateral and medial aspect of the distal cannon, between the DDFT and SL, just proximal to the fetlock region (on weight-bearing, the skin at this site is approximately 90° to the ground, while just at the proximal aspect of the DFTS, the skin abruptly changes the angulation to 60° to 70° to the ground). The angulation change is also observed with the limb lifted off the ground. Our results also suggest that using the proximal observable aspect of the DFTS as a landmark for the selection of the injection site has the potential to significantly decrease the risk of inadvertent penetration of the DFTS when using the TLPB.

Even though the contrast medium diffusion could have been monitored more closely at multiple time points, a previous study[7] has demonstrated that most of the proximal diffusion is observed 10 minutes after injection. Moreover, during orthopedic examinations it is common practice to evaluate the perineural analgesia at 10 minutes or less, and only in the case of the proximal and larger nerves, like the tibial nerve, has it been recommended to evaluate the response at a later time point.[1] On the basis of the aforementioned studies and the significant proximal diffusion 10 minutes postinjection observed in our ex vivo study, we decided to evaluate diffusion at a single time point after injection during the in vivo study. We also believe that further evaluations at other time points will not add clinically significant information to this paper. Intravascular injections of anesthetic solution have been reported as a possible cause of unsuccessful perineural analgesia techniques.[1] Even though intravascular injections usually do not cause complications, they must be considered when regional blocks fail to desensitize a region. During the ex vivo study, 1 of 20 injections using the MASB were intravascular while none were observed using the TLPB and no significant difference was found between techniques.

It must also be considered that the viscosity of the contrast medium (iohexol molecular weight, 821 g/mol) is higher than the local anesthetics (mepivacaine molecular weight, 246 g/mol) traditionally used for perineural analgesia and could potentially diffuse less efficiently than mepivacaine. Interestingly, our ex vivo study using stained mepivacaine presented a very similar proximal diffusion when compared with the contrast medium in the in vivo study. Previous studies have reported the use of a mixture of contrast medium and mepivacaine; nevertheless, it is unknown whether this has a negative or positive effect on diffusion. Due to this, we decided to test both mepivacaine/methylene blue and contrast medium using ex vivo and in vivo models, respectively. Even though in vivo and ex vivo studies cannot be compared directly, this observation suggests that mepivacaine will most likely behave similarly in real clinical cases than what was observed with the contrast medium. These results support the use of the MASB, since it seems that this nerve block modification would possibly allow the clinician to localize the source of pain more efficiently, presenting less proximal diffusion than the TLPB.

The in vivo study was performed using a crossover study design. This design allowed us to evaluate many variables and interactions from which only the technique had a significant effect on proximal diffusion. Side

(lateral or medial) and first or second phase of the crossover study (same animal, same limb, but different technique on a different day) did not significantly affect diffusion. Even though experimental models do not exactly represent what happens in a clinical case, the contrast medium diffusion models have proven to be helpful for understanding the interaction between the injectate and the tissues.[3–9] These models help the clinician to tailor new blocking strategies that minimize proximal diffusion or at least to understand which structures could be inadvertently desensitized or penetrated.

Modification of the traditional technique for injecting the palmar metacarpal nerves is difficult to achieve.[9] Even though there is an important risk of inadvertently penetrating the fetlock joint when using the traditional technique,[6,9] it has been reported that injections in more proximal sites are not well tolerated.[9] It has been also reported that in most of the palmar metacarpal nerve block injections the contrast medium patch distributed diffusely around the injection site, with no major proximal diffusion.[6] Therefore, no attempt was made in this study to modify the palmar metacarpal nerve block technique.

Even though it has been demonstrated that the injectates extend to no more than 5 cm when performing the low palmar nerve block,[9] this proximal diffusion has the potential to inadvertently desensitize structures of the mid-metacarpal region.[6,9] Our study suggests that the MASB (in vivo and ex vivo) diffuse consistently just proximal to the DFTS, decreasing the risk of proximal diffusion and inadvertent desensitization. Even though this study was only performed in the hind limbs, it is likely that the local anesthetic diffusion would behave similarly in the forelimbs.

There were several limitations in this study. Ex vivo studies most likely underestimate the diffusion in the tissues due to the lack of active perfusion. In the in vivo model, a limited number of animals were used; nonetheless, it was compensated by the crossover study design. The animals used in this study were relatively small; therefore, it is likely that to achieve similar diffusion in larger animals, a larger volume of anesthetic may be needed. Due to the high viscosity of the contrast medium, it is possible that our study underestimated the proximal diffusion that can occur in real clinical cases when injecting local anesthetics. Nonetheless, our results suggest that the diffusion of mepivacaine and contrast medium might be similar. The MASB was not compared to a traditional abaxial sesamoid block to determine whether there is a significant difference on proximal diffusion between both. The results of our ex vivo study suggest that there is a significant difference in the diffusion between the BSB and MASB. The efficacy of this technique could not be assessed since no local anesthetic was used; nevertheless, the abaxial sesamoid block is a straightforward and reliable technique and it is not likely that the modifications will affect these characteristics. The contrast medium diffusion was only evaluated at 10 minutes; nonetheless, it has been previously demonstrated that most of the diffusion happens at this time point.

In conclusion, the MASB allows the operator to safely inject the plantar nerve in the hind limbs, consistently reaching the proximal margin of the proximal pouch of the DFTS. This technique also presents a very low incidence of inadvertent intrasynovial or intravascular injections. It was demonstrated that the MASB presented less proximal diffusion than the TLPB but significantly more than the BSB. Our results suggest that the use of the MASB might decrease the chances of presenting undesired proximal diffusion and therefore less likelihood of inadvertently desensitizing structures of the mid-cannon region.

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Disclosures

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