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CLINICAL RESEARCH

# Efficacy of needle and endoscopic lavage on the recuperation of microspheres from the adult equine metacarpo−/metatarsophalangeal joint and digital flexor tendon sheath

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## Abstract

**Objectives:** To measure microsphere recovery following needle-through-and-through lavage (NTAT) of the metacarpo−/metatarsophalangeal joint (fetlock) and digital flexor tendon sheath (DFTS) compared to endoscopic lavage (EL).

**Study design:** Ex vivo experimental study.

**Animals:** Adult equine cadavers immediately following euthanasia ($n = 10$).

**Methods:** Colored 15 μm microspheres (2 million) were injected into fetlock joints and DFTS. Synovial structures were assigned to NTAT or EL groups. Each lavage was performed using 5 L of 0.9% NaCl, sequentially collecting egress fluid for microsphere quantification. Recovery was compared using a full-factorial general linear model.

**Results:** There was a significant effect of the liter of egress fluid and microsphere recovery in both fetlocks ($p < .01$) and DFTS ($p < .01$), with most microspheres recovered in the first 2 L (79%–83%) for both techniques. More microspheres were recovered in the first liter using NTAT than EL ($p < .01$) in both fetlocks (659 883 ± 20 820 vs. 567 601 ± 24 452) and DFTS (644 341 ± 17 460 vs. 550 637 ± 38 022). No difference in total recovered microspheres was observed between NTAT lavage of fetlock (981 600 ± 46 839) and DFTS (957 419 ± 45 729) across 5 L ($p = .88$).

**Conclusion:** Needle-through-and-through lavage was more effective than EL at recovering microspheres in the first liter from cadaveric equine fetlock joints and DFTS. Both techniques demonstrated comparable efficacy between fetlock and DFTS in microsphere recovery following increased lavage volumes.

**Clinical significance:** Needle-through-and-through lavage (NTAT) is a viable alternative for suspected synovial contamination when EL is delayed or not

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feasible. This study does not evaluate NTAT's efficacy for treating established sepsis or removing pannus/foreign bodies.

## 1 | INTRODUCTION

Sepsis of synovial structures, such as joints and tendon sheaths, are a common emergency encountered in equine practice that can be both performance-limiting and life-threatening.[1–3] Synovial sepsis is the result of introduction of microorganisms into the synovial cavity, which can occur via hematogenous spread, wounds extending into the synovial structure, or iatrogenically through intra-articular (IA) injection or surgery.[4,5] The distal limb of horses, particularly the lower third of the metacarpus and metatarsus, is more susceptible to synovial sepsis than the proximal limb. This heightened risk arises from limited protection by surrounding soft tissues, making wounds or punctures in this area more likely to contaminate nearby synovial structures.[6]

Septic arthritis and septic tenosynovitis have a similar etiology with similar clinical signs. In both disorders, large amounts of inflammatory mediators, antigens and inflammatory enzymes are released. Subsequently, neutrophilic phagocytosis of microorganisms leads to the release of lysosomes, collagenases and cytokines such as interleukin-1 beta (IL-1β) and tumor necrosis factor-alpha (TNF-α). These have proteolytic and degenerative effects that can potentially result in profound and irreversible damage to the intra-synovial structures.[7] Coagulation and fibrinolytic pathways are also activated which, when combined with the other mechanisms, results in elevated intrasynovial pressure, leading to decreased blood flow to the synovium, accumulation of fluid within the synovial structure, and pain. Fibrin deposits in the affected synovial structures provide a matrix for microorganisms to adhere to and multiply.[7,8] This fibrinocellular conglomerate, commonly known as pannus, acts as a nidus for infection, which should be removed to prevent ongoing infection.[5]

Prompt diagnosis and effective treatment are essential to eliminate infection and minimize the extent of damage caused within the synovial structures.[9] In clinical scenarios, a dual approach that combines both systemic and local broad-spectrum antimicrobial therapies is recommended in conjunction with synovial lavage to address infection and inflammation secondary to contamination of the synovial space.[9–11] Several surgical techniques can be used to treat synovial sepsis, all with the same objectives: high-volume lavage and physical removal of microorganisms, inflammatory mediators and debris.[11] Endoscopic lavage (EL) is the preferred approach for treatment of synovial sepsis as it allows high volume lavage, removal of fibrin and foreign debris as well as the evaluation of the intra-articular and soft tissue structures, and removal of any osteochondral fragments.[12] In horses, EL is typically performed under general anesthesia and requires specialized surgical training, appropriate facilities, and endoscopic equipment. Consequently, EL is associated with higher costs compared to other treatment options.[11]

Needle through-and-through lavage (NTAT) is a comparatively less expensive method of synovial lavage. It can be performed under general anesthesia or, in some cases, under standing sedation.[13] Minimal training and no specialized equipment are required, making it a much more accessible option for veterinarians in general practice.[14] Needle lavage is used in foals with acute synovial sepsis if there are no radiographic bony changes, in financially constrained cases, or when endoscopic procedures are not feasible.[11] However, in advanced or chronic cases, needle lavage techniques are less effective due to fibrin deposits and pannus within the inflamed synovial structures, which clog the needles and obstruct the flow of lavage fluid, leading to poorer clinical outcomes.[15] Despite these potential concerns, retrospective studies conducted on both foals and adult horses have demonstrated that the survival rate to discharge in cases of synovial sepsis treated with NTAT techniques is similar to that of cases receiving EL.[15–17]

For many equine practitioners, referring patients with synovial sepsis to facilities with EL capability is not an option due to geographical location, transportation issues, or financial considerations. A delay in treating these conditions could reduce the prognosis for the horse's return to previous athletic ability or survivability[3]; thus, establishing the efficacy of NTAT lavage compared to EL in multiple synovial structures would enable equine practitioners to make better evidence-based recommendations to their clients.

In a research environment 15 μm microspheres can be used to replicate white blood cells or debris present in synovial contamination due to the comparable size to equine granulocytes.[18] Using this technique, one study demonstrated superiority in microsphere recovery using 14-gauge needles, including 2 egress needles, when compared to EL with a single egress cannula in the equine tarsocural joint.[14] Currently, no studies exist evaluating the relative efficacy of NTAT and EL on the most commonly affected synovial structures in the distal limb, namely the fetlock and DFTS. Therefore, the aim of the

present study was to compare the efficacy of microsphere recovery from the metacarpo−/metatarsophalangeal (fetlock) joint and the digital flexor tendon sheath (DFTS) using EL and NTAT techniques. We hypothesized that there would be no difference in microsphere recovery in either synovial structure using EL and NTAT techniques.

## 2 | MATERIALS AND METHODS

A total of 10 horses, with no history of disease in the fetlock joints or digital flexor tendon sheath, were donated to the School of Veterinary Science at Massey University, New Zealand, and humanely euthanized for reasons unrelated to the study. In each horse, the fetlocks and DFTS of both the fore- and hindlimbs were randomly assigned (20 matched pairs per group) to one of two experimental groups (NTAT or EL) using a random number generator (www.randomizer.org). A single investigator (CB) performed all procedures.

Immediately following euthanasia, horses were positioned in dorsal recumbency and the distal aspect of each limb was clipped. Each fetlock and DFTS were injected with 0.4 mL of a solution containing 2 million 15 μm microspheres ($5 \times 10^6$ microspheres/mL, Red/Yellow dyed PST, Lab 261, California) followed by 30 mL of 0.05% polyoxyethylensorbitan monooleate solution (Tween 80, Sigma-Aldrich, Missouri) to reduce clumping of microspheres. To prevent microsphere loss during the distention of synovial structures, digital occlusion of the needle hub was performed while transferring between syringes and digital pressure was applied to the injection site immediately following removal of the needle. Tendon sheaths were injected with yellow microspheres using the lateral palmar/plantar axial seasmoidean approach.[19] Fetlocks were injected with red microspheres into the lateral proximal palmar/plantar pouch.[12] Each limb was then manipulated by extension and flexion for 5 min to ensure microsphere distribution throughout the synovial structures prior to lavage. The limbs were then secured to surgical table cross-bar attachments and maintained with moderate flexion of the fetlock joint.

### 2.1 | Instrument setup for lavage procedures

#### 2.1.1 | Endoscopic lavage procedures

Endoscopic lavage of the fetlock joint was approached via stab incision (No 11, Swann-Morton, Sheffield, UK) into the distended dorsal pouch in the proximolateral quadrant. An arthroscopic cannula was introduced using a blunt conical obturator perpendicular to the skin and then parallel to the articular surface of the third metacarpus/tarsus before being advanced proximally and then distally once over the sagittal ridge.[20] The obturator was then replaced with a 4 mm diameter, 30° working angle, 175 mm long arthroscope (Karl Storz Veterinary Endoscopy, Tuttlingen, Germany) and the fluid ingress line was attached. An instrument portal was created in the proximomedial pouch of the dorsal fetlock for the insertion of a 3.2 mm egress cannula (Karl Storz Veterinary Endoscopy) perpendicularly to the skin and parallel to the articular surface of the third metacarpus/tarsus. In a routine arthroscopy the palmar/plantar pouch is also entered. Instead, a 14-gauge 2-inch needle (Monoject, Covidien, Dublin, Ireland) was placed into the proximopalmar/plantar recess parallel to the lateral condyle of the third meta-carpus/tarsus, between the condyle and the articular surface of the lateral sesamoid bone prior to the lavage (Figure 1A).[21] While performing the lavage, a systematic assessment of the visible structures within the joint was performed in a manner similar to routine arthroscopy of the fetlock joint.[20]

Endoscopic lavage of the DFTS was approached via a stab incision (No. 11, Swann-Morton, Sheffield, UK) into the distended pouch between the palmar/plantar annular ligament and the proximal digital annular ligament at the base of the proximal lateral sesamoid bone approximately 5 mm palmar/plantar to the digital neurovascular bundle.[22] A tenoscopic cannula was introduced using a blunt conical obturator and directed proximally through the fetlock canal into the proximal DFTS. The obturator was then replaced as for the fetlock procedure. An instrument portal was made in the corresponding location on the medial aspect of the DFTS under tenoscopic guidance. A 3.2 mm egress cannula (Karl Storz Veterinary arthroscopy) was then introduced initially perpendicular to the skin, then proximally through the fetlock canal into the proximal dorsal recess of the DFTS. An additional egress portal was made by introducing a 14 gauge 2-inch needle (Monoject, Covidien) into the lateral proximal pouch of the tendon sheath under tenoscopic guidance (Figure 1B). While performing the lavage, a systematic assessment of the visible structures was performed in a similar manner to a routine tenoscopy of the DFTS.[22]

#### 2.1.2 | Needle through-and-through lavage procedures

Needle-through-and-through lavage was performed using 14 gauge 2-inch needles. A needle, attached to the fluid ingress line, was placed into the distended dorsal pouch in the proximolateral quadrant of the fetlock, another needle

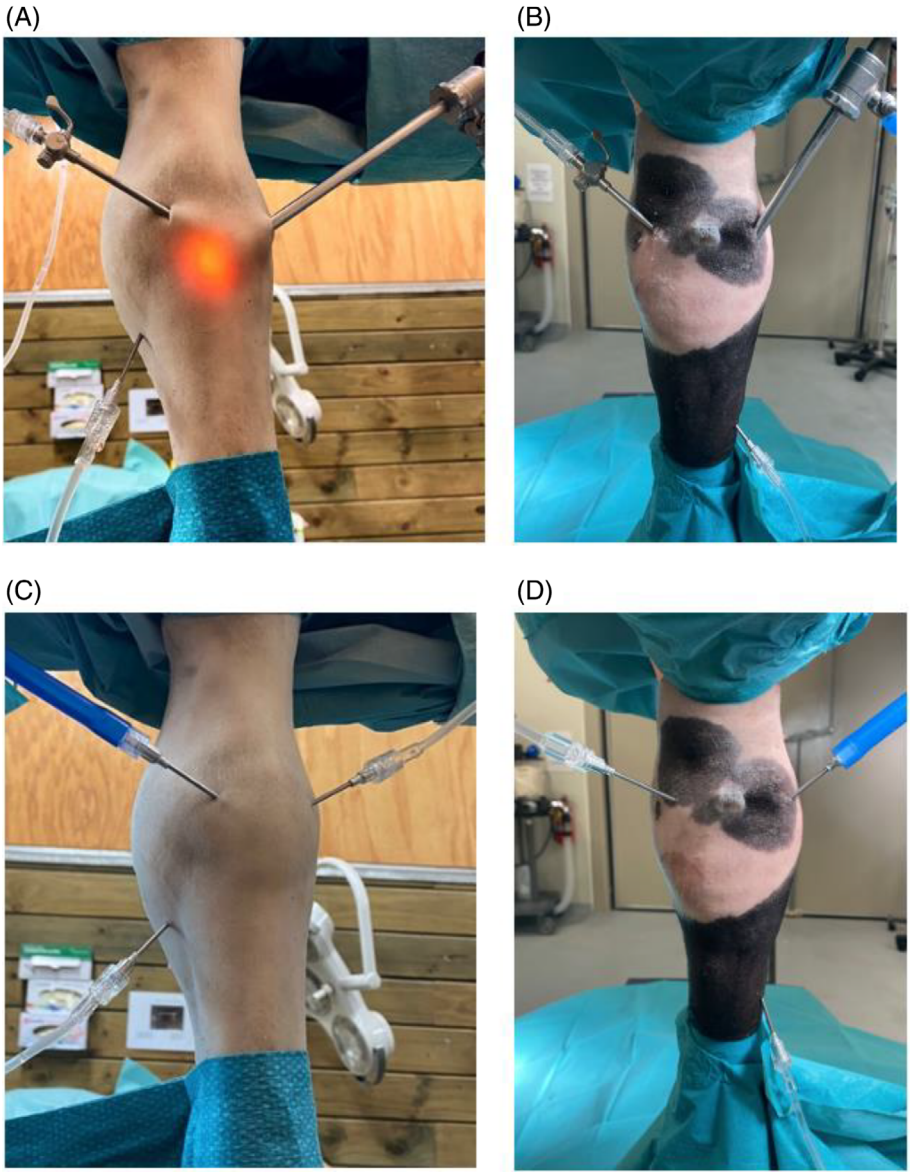


**FIGURE 1** Photographs show the placement of endoscopic lavage (EL) and needle-through-and-through (NTAT) portals on the fetlock (A&C) and digital flexor tendon sheath (B&D) in a forelimb. (A) EL of the fetlock, with the cannula and endoscope in the proximolateral quadrant, an egress cannula in the proximomedial quadrant, and an egress needle in the medial palmar pouch. (B) EL of the digital flexor tendon sheath (DFTS), with the cannula and portal at the proximal lateral sesamoid, an egress cannula at the proximal medial sesamoid, and a needle in the lateral proximal pouch. (C) NTAT of the fetlock joint using an ingress needle in the proximolateral quadrant and an egress needle in both the proximomedial quadrant and medial palmar pouch. (D) NTAT of the DFTS, with an ingress needle at the proximal lateral sesamoid and egress needles at the proximal medial sesamoid and lateral proximal pouch.

was placed into the dorsal pouch of proximomedial quadrant of the fetlock. A third needle was placed through the collateral seasmoidean ligament parallel to the palmar/plantar aspect of the lateral condyle of the third metacarpus/tarsus, between the condyle and the articular surface of the lateral sesamoid bone (Figure 1C).

For lavage of the DFTS, a needle, attached to the fluid ingress line, was placed into the distended lateral pouch between the palmar/plantar annular ligament and the proximal lateral sesamoid bone approximately 5 mm palmar/plantar to the digital neurovascular bundle. A second needle was placed into the medial proximal pouch using the same landmarks, and a third needle was placed into the proximolateral portion of the sheath (Figure 1D).

## 2.2 | Lavage procedures

To maximize fluid and microsphere recovery for quantification, all egress cannulas and needles were placed

after attachment to high-flow extension lines (150 cm extension line, Kruuse, Langeskov, Denmark). Additionally, skin incisions in the EL procedures were kept as small as possible to facilitate effective passage of the obturator and egress cannula while minimizing fluid leakage around the instruments.

A total of 5 L of 0.9% sodium chloride (1 L, 0.9% NaCl USP, Baxter Healthcare Corporation, Illinois) was placed through a fluid irrigation pump (SCB Hamou Endomat, Karl Storz Veterinary Endoscopy) attached to the fluid ingress line. The pump was set to a maximal pressure of 120 mmHg and a fluid flow rate of 600 mL/min. High-flow fluid extension lines were used to collect the egress fluid into containers. Additionally, 5 mL of polyoxyethylensorbitan was added to each liter of egress fluid to prevent microsphere clumping before processing.

## 2.3 | Sample processing

Each liter sample was pipetted into 4 × 250 mL wide-mouthed centrifuge tubes to be centrifuged at 2000 *g* for 5 min at room temperature. The supernatant was then siphoned at a level well above the microsphere pellet. The microsphere solution from the four tubes was combined and placed into a 100 mL centrifuge tube. For collection of any remaining microspheres, the empty tubes were washed with 95% ethanol, and the wash solution was added to the 100 mL centrifuge tube. The process was repeated with centrifugation at 1500 *g* for 5 min, siphoning and washing into 15 mL tubes. The solution was again centrifuged at 1500 *g* for 5 min, siphoned and 0.5 mL of ethanol was added to the pellet for reconstitution before transfer into a 1.5 mL vial. Solutions were topped up to a total volume of 1 mL with 95% ethanol before allowing evaporation at room temperature, leaving a small dry sample at the base of the vial.

Dye was extracted from the microspheres by adding 100 μL of n-n dimethylformamide (Macron Fine Chemicals, Center Valley, Pennsylvania) to each sample followed by a minimum of 30 s of vortex agitation and 3 min of centrifugation at 1500 *g*.[23]

To quantify any loss of microspheres during sample processing, a solution containing 100 000 blue 15 μm polystyrene microspheres (Blue dyed PST, Lab 261, California), was added to each liter of egress fluid at the end of the procedure. The blue dye was measured at the same time as the corresponding red/yellow microspheres within the samples to determine the number of microspheres lost during sample processing.

## 2.4 | UV-U spectrometry

A UV-U spectrometer (Jenway 7315 Spectrophotometer, Staffordshire, UK) was used to analyze the samples at peak absorbances of 414 nm (yellow) or 515 nm (red), to correspond to the microspheres used for DFTS or fetlocks, respectively. All samples were also analyzed for peak absorbances of 644 nm (blue) to assess microsphere loss during the sample processing stages. The UV-U spectrometer was initially calibrated using a blank sample of *n-n* dimethylformamide and recalibrated using the blank n-n dimethylformamide between analyses for each peak absorbance.

The lowest absorbance units (AU) result for all three colors that could be reliably distinguished from background noise was 0.05 AU, therefore samples yielding results lower than 0.05 AU were recorded as 0.05 AU.

## 2.5 | Statistical analysis

Data were collated using Microsoft Office 365 Excel for Mac (version 16.90.2) and analyzed statistically using IBM SPSS (version 29.0.2.0, Armonk, New York). The quantity of recovered microspheres was analyzed using a full factorial general linear model. In this model, egress liter number, forelimb versus hindlimb, fetlock versus DFTS, and NTAT versus EL were fitted as fixed effects. Pairwise comparisons within the fixed effects were examined using a least significant difference test. A Bonferroni post hoc test was used to adjust for multiple comparisons. For all analyses, the level of significance was set as $p < .05$. Furthermore, the quantity of blue microspheres obtained in each sample was compared using a one-way ANOVA with multiple comparisons, to evaluate any potential effects of sample processing on the quantity of microspheres measured following collection.

# 3 | RESULTS

A total of 40 fetlocks and 40 DFTS from 10 horses were included in the study from seven geldings and three mares. The median age of the horses was 10.3 years (range: 3–21 years), and the median weight was 501.5 kg (range: 402–670 kg). Breeds included seven Thoroughbreds, one New Zealand Stationbred, one Pinto, and one Clydesdale cross. There was no difference between the number of microspheres recovered in the fore- and hindlimbs with any of the egress fluid liters, for both techniques ($p = .56$). Estimated marginal means of all variables are presented in Table 1.

There was a significant effect of the liter of egress fluid on the number of microspheres obtained in both the fetlocks ($p < .01$) and the DFTS ($p < .01$) (Figure 2).

**TABLE 1** Estimated marginal means of the number of microspheres ((±SD) recovered per liter of egress fluid for each variable in the study generated using a full factorial general linear model.

| Liter of egress fluid | | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|---|
| Limb | Forelimb | 637 802 ± 1510 | 143 194 ± 1510 | 81 690 ± 1510 | 49 875 ± 1510 | 46 834 ± 1510 | 191 879 ± 675 |
| | Hindlimb | 634 677 ± 1510 | 14 691 ± 1510 | 83 185 ± 1510 | 50 621 ± 1510 | 46 834 ± 1510 | 192 447 ± 675 |
| Site | Tendon | 620 703 ± 1510 | 141 789 ± 1510 | 80 261 ± 1510 | 49 662 ± 1510 | 46 160 ± 1510 | 195 715 ± 675 |
| | Fetlock | 651 777 ± 1510 | 148 323 ± 1510 | 84 613 ± 1510 | 50 834 ± 1510 | 47 509 ± 1510 | 196 615 ± 675 |
| Method | NTAT | 644 305 ± 1510 | 1 445 567 ± 1510 | 84 613 ± 1510 | 49 662 ± 1510 | 46 160 ± 1510 | 190 601 ± 675 |
| | EL | 628 175 ± 1510 | 1 444 545 ± 1510 | 80 261 ± 1510 | 50 834 ± 1510 | 47 509 ± 1510 | 193 725 ± 675 |
| Total | | 636 240 ± 1068[a] | 145 056 ± 1068[b] | 82 437 ± 1068[c] | 50 248 ± 1068[c] | 46 834 ± 1068[c] | |

Abbreviations: EL, endoscopic lavage; NTAT, needle-through-and-through.
[a,b,c]Superscripts indicate differences in microspheres recovered between liters of egress fluid ($p \leq .05$).

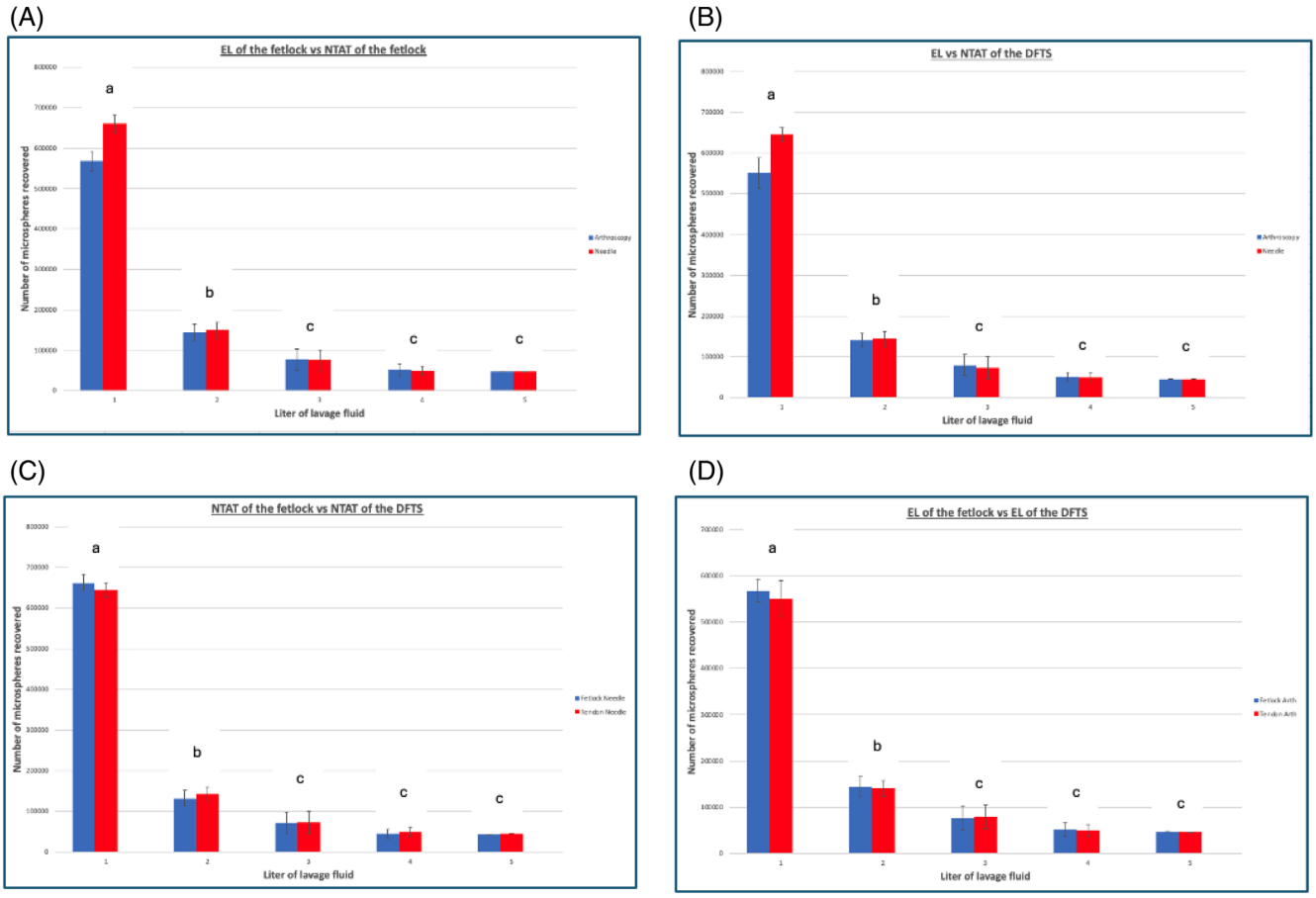


**FIGURE 2** Mean number of microspheres (±SD) recovered per liter of egress fluid. (A) Endoscopic lavage (EL) of the fetlock versus needle-through-and-through (NTAT) of the fetlock. (B) EL of the digital flexor tendon sheath (DFTS) versus NTAT of the DFTS. (C) EL of the fetlock versus EL of the DFTS. (D) NTAT of the fetlock versus NTAT of the DFTS. Superscripts ([a,b,c]) indicate differences in microspheres recovered between liters of egress fluid ($p \leq .05$).

For the NTAT and EL techniques, 67% and 64% of the total microspheres obtained were present in the first liter, respectively, this was significantly more than in subsequent liters ($p < .01$). In the second liter of egress fluid, 16% and 15% of the recovered microspheres were present, this was significantly more than subsequent

liters ($p < .01$). There was no significant difference in the number of microspheres obtained in liters 3–5 for both structures using both techniques ($p = .15$) (Figure 2).

### 3.1 | Fetlocks

In the fetlock, there were significantly more microspheres obtained from the first liters of egress fluid in the NTAT technique (659 883 ± 20 820) compared to the EL technique (567 601 ± 24 452; $p \leq .01$) (Figure 2A). There was no significance between the microspheres obtained in the subsequent liters of lavage fluid when comparing the two techniques ($p = .39$).

### 3.2 | Digital flexor tendon sheaths

There were significantly more microspheres obtained in the first liter of egress fluid from NTAT (644 341 ± 17 460) compared to EL (550 637 ± 38 022; $p \leq .01$) (Figure 2B). There was no significant difference between the microspheres obtained in the subsequent liters of egress fluid between the two techniques ($p = .45$).

### 3.3 | Fetlock versus digital flexor tendon sheath

Irrespective of the synovial structure, the majority of microspheres recovered were present in the first liter of egress fluid. There was no significant difference between the number of microspheres recovered from NTAT of the fetlock joint (659 883 ± 20 820) compared to the NTAT of the DFTS (644 341 ± 17 460) for this first liter ($p = .44$) (Figure 2C). The total number of microspheres recovered from the NTAT of the fetlock (981 600 ± 46 839) was not significantly different from the total number of microspheres recovered from the DFTS (957 419 ± 45 729) across five liters of lavage fluid ($p = .88$). Similarly, there was no difference in the number of microspheres recovered in the first liter of lavage fluid for EL when comparing the fetlock (567 601 ± 24 452) and DFTS (550 637 ± 38 022), ($p = .24$) (Figure 2C). The total number of microspheres recovered from the EL of the fetlock (951 110 ± 46 002) was not significantly different from the total number of microspheres recovered from the DFTS (934 886 ± 38 392) across 5 L of lavage fluid ($p = .85$).

As an internal control for microsphere loss during sample processing blue microsphere recovery was measured. There was no difference between the number of blue microspheres recovered between any of the egress fluid liters obtained from either technique across both synovial structures ($p = .51$). Of the 100 000 blue microspheres, the mean percentage recovered from the DFTS was 68 ± 4% and 68 ± 5%, respectively. For the fetlock, mean microsphere recovery was 67 ± 4% for both techniques. This demonstrated calculated losses between 28% and 36% of the microspheres during the sample processing phase.

## 4 | DISCUSSION

The present study demonstrates that NTAT lavage is an effective method for removing microspheres from healthy nonclinical fetlocks and DFTS in recently deceased horses. The findings of this study demonstrate that NTAT lavage efficacy is comparable to EL techniques when using 5 L of lavage fluid, a comparable technique to that used in clinical cases of synovial contamination. These findings support our initial hypothesis that techniques would not differ in efficacy. Furthermore, it was also demonstrated that there was no difference in the efficacy of NTAT lavage when comparing the fetlock and DFTS ($p < .01$), supporting our secondary hypothesis.

Sepsis of the DFTS is believed to respond better to EL rather than medical management or needle lavage techniques.[24] The theory is that NTAT lavage is not as effective at flushing the DFTS due to anatomical structures such as the blind-ended pouches of the manica flexora, which can form synovial fluid pools. It is believed that these synovial pools are not adequately lavaged without direct endoscopic visualization of the pouches.[25] In the current study, it was demonstrated that despite the relative anatomical complexity of the DFTS, NTAT lavage was as effective at flushing microspheres from this structure as EL. It was further demonstrated that the overall efficacy of NTAT lavage of the DFTS was comparable to NTAT of the fetlock joint, which suggests that anatomical differences might not be as relevant as initially thought.

Assessing whether these procedures could be effectively performed on standing horses was not included in this study, as our model simulated horses in dorsal recumbency for a procedure under general anesthesia. There are multiple reports on performing standing procedures within the fetlock joint and DFTS, which could be used as a reference when attempting to perform NTAT lavage under standing sedation in these structures.[26,27] It is worth noting that the NTAT lavage procedure in the DFTS is more technically challenging than in the fetlock. The authors found that even slight movements of the needles within the tendon sheath profoundly affects the flow rate. Performing this procedure on a standing horse could be challenging and relies on patient

compliance. In one report describing a standing approach to the DFTS, for desmotomy of the palmar/plantar annular ligament in horses, a commercial leg saver splint was used to hold the fetlock in partial flexion while weight-bearing.[28] This facilitated entering and maneuvering within the DFTS and could potentially be used to facilitate the standing NTAT lavage procedure. Further studies into the efficacy of these procedures in standing horses are required.

The current study demonstrates that the largest portion of microspheres (79%–83%) is recovered in the first and second liters of egress fluid for both EL and NTAT lavage techniques. This demonstrates that the majority of debris would be removed in the first 2 L of lavage fluid through the fetlock and DFTS. These findings are comparable to those obtained in a similar study that assesses both lavage techniques in equine tarsocural joints.[9] Smaller total lavage volumes would be advantageous if these procedures were performed outside of the hospital environment or on compromised patients, as this would result in reduced anesthetic time. Furthermore, the shorter procedure time and simpler equipment could allow the use of this technique in the standing horse. Typically, with standing procedures, due to horse compliance and movement despite appropriate nerve or joint blocking, a smaller total lavage volume is achieved in comparison to either technique performed under general anesthesia. However, in clinical cases of synovial sepsis, when diffuse pannus and fibrin deposits are present throughout the structures, larger lavage volumes might be required, along with larger egress portals and the use of instruments to remove pannus and debris.

In routine arthroscopic inspection and lavage of septic joints, all compartments are visualized to ensure no potential nidus for infection remains, and in DFTS additional portals are created to allow complete visualization of certain aspects of the sheath and soft tissue structures within.[26] An increased number of egress portals has been speculated to increase lavage efficacy.[14] Therefore, in clinical cases the movement of the endoscope between multiple portals, along with the elevated egress flow rates through portals in the absence of resistance from instruments, might contribute to a more thorough lavage. In the present study, movement of equipment between portals would have led to loss of egress fluid, potentially resulting in an artificial reduction in microsphere recovered per liter of egress fluid. To simulate the endoscopic portals used in clinical cases, 14-gauge needles attached to extension lines were used. It is possible that the smaller diameter of the needles, in comparison to a conventional portal or egress cannula, might have affected egress flow and, consequently microsphere recovery. Additionally, the use of extension lines to optimize fluid recovery for analysis might have altered the flow of egress fluid.

In the present study, the number of microspheres recovered in the first liter was lower for EL samples than for NTAT lavage due to fluid loss during the creation of surgical portals and placement of the obturator and egress cannula. Efforts were undertaken to mitigate the possible fluid loss at this stage of the procedure; however, some losses were unavoidable. This study has demonstrated that the largest proportion of microspheres was recovered in the first liter of egress fluid across all structures and techniques. Consequently, the loss of a relatively small amount of fluid during this preliminary phase might correspond to larger microsphere losses, potentially affecting these results.

Despite the increased number of microspheres obtained via NTAT lavage, the authors the, additional benefits of EL compared to NTAT maintain EL as the gold standard for investigating and treating septic synovial structures as endoscopy facilitates direct visualization of the synovial space and allows assessment of articular cartilage or soft tissue structures for concurrent injury.[27] This assessment allows for a more accurate prognosis on recovery or return to athletic function to be made. In addition, through endoscopy, foreign material and pannus can be located and removed from the synovial space, reducing the chances of ongoing sepsis and the need for repeated lavage.[29]

A limitation of the present study was the use of only one investigator (CB), who was an ECVS surgical resident experienced in endoscopic surgery at the time of the investigation. It might have been beneficial to have the NTAT lavage procedures performed by practitioners of variable experience to demonstrate the practical application of these procedures in a first-opinion clinical environment. Furthermore, this study only included clinically normal synovial structures. Proliferative or inflamed synovium, which may occur with any synovial sepsis, is likely to hinder or obstruct the outflow of fluid through the needles. Additionally, excessive pannus or fibrin deposits could further decrease fluid outflow. As discussed previously, loss of fluid during the creation of surgical portals and the placement of instruments in the EL procedures might have resulted in the loss of microspheres. Furthermore, the extension lines and needles used in place of conventional portals, might have affected microsphere clearance. A further limitation of this study was the absence of Cob-type breeds, wherein needle access to the DFTS can often be challenging. The inclusion of a broader range of equine breeds could have facilitated a more accurate evaluation of the practical application of these techniques. Additionally, despite steps taken to minimize sample disturbance during processing and maximize microsphere recovery, the loss of microspheres during the sample processing phase was

between 28% and 36% in the present study. Nonetheless, the losses were consistent across samples, and findings remain applicable for comparison of the various lavage techniques employed on the two synovial structures.

## 5 | CONCLUSIONS

In the present study we demonstrate that NTAT lavage is an effective therapeutic strategy for the irrigation of contaminated fetlocks and DFTS in adult horses and that the majority of effective lavage is completed in the first 2 L (79%–83%). It is important to note that the results pertain to clinically normal synovial structures and might not accurately reflect the treatment of established sepsis with bacterial sequestration, pannus accumulation, and foreign material. Therefore, endoscopic lavage is still considered the gold standard technique as it allows visualization of articular surfaces and facilitates the removal of pannus or osteochondral fragments within the synovial cavity. However, NTAT lavage has been shown to achieve comparable clearance to EL in fetlocks and DFTS without proliferative synovium, pannus, or fibrin formation. These findings suggest that needle through-and-through lavage is a viable alternative to EL, especially in situations where EL might not be readily available.

### AUTHOR CONTRIBUTIONS

Beggan CP: Contributed to the study concept and design, performed all the surgical procedures, processed all samples, statistical analysis, and result interpretation, and drafted and revised the manuscript. Panizzi L, DACVS (Large Animal): Contributed to the interpretation of results and drafts, and revised the manuscript. Oliver LJ, DACVS (Large Animal): Contributed to the study design and interpretation of data and was responsible for scientific editing of the manuscript.

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### CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest.

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