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CLINICAL RESEARCH

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Accuracy and safety of stifle arthrocentesis and injection based on two established and two new landmarks: Ex vivo study in dogs

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Abstract

Objective: To determine the accuracy and safety of two established landmark-based techniques and two novel techniques for stifle arthrocentesis in dogs.

Study design: Ex vivo prospective study.

Animals: A total of 32 paired canine cadaver pelvic limbs.

Methods: An electronic survey assessed technique prevalence among surgeons. Pelvic limbs ($n = 32$) were randomized to one of four techniques; lateral intercondylar notch (LINC), infrapatellar (INFRA), suprapatellar (SUPRA), or proximal lateral parapatellar pouch (POUCH) technique, with $n = 8$ per group. Repositions, attempts, and synovial fluid presence were recorded. Stifle arthrography assessed accuracy. India ink assay assessed iatrogenic articular cartilage injury (IACI). Omnibus tests were used ($p < .05$), with post hoc Bonferroni-correction ($p < .0083$).

Results: A total of 40 surgeons responded, with LINC most commonly used (35/40, 87.5%). All tested techniques were accurate (8/8, 100%, $p > .9$). INFRA and SUPRA required more needle repositions (median 3 and 2, respectively) than LINC and POUCH (median 1 for both), ($p = .001$). LINC and SUPRA produced no IACI, INFRA (6/8, 75%) and POUCH (3/8, 37.5%) ($p = .007$). Over half of IACI produced with INFRA exceeded 10 mm^2 in area, all on weightbearing cartilage ($p = .041$). POUCH injuries occurred exclusively on non-weightbearing cartilage ($p = .041$).

Conclusion: LINC and INFRA are currently used clinically and were accurate; however, INFRA required increased repositions and had high IACI rates on

Abbreviations: IACI, iatrogenic articular cartilage injury; INFRA, infrapatellar; LINC, lateral intercondylar notch; POUCH, proximal lateral parapatellar pouch; SUPRA, suprapatellar.

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weightbearing cartilage. Two novel techniques were feasible and accurate; SUPRA was safe with no IACI, while POUCH had high IACI risk on non-weightbearing cartilage.

Clinical significance: SUPRA may be a safer alternative than current established techniques and warrants further clinical investigation. INFRA carries high IACI rates.

1 | INTRODUCTION

Stifle arthrocentesis and injection is commonly performed in dogs for the acquisition of synovial fluid for diagnostic purposes, and for intra-articular administration of therapeutic agents. Synovial fluid can be analyzed cytologically to differentiate joint disease such as osteoarthritis from infective arthritis and immune-mediated polyarthritis.[1,2] Intra-articular injections of various compounds may reduce inflammation, slow degeneration of the joint and decrease pain.[2–4] For stifle aspiration and injection, precise intra-articular localization of the needle is crucial. Failure to accurately target the intra-articular space reduces the efficacy of intra-articular therapy, and increases the risk of complications.[5]

Stifle arthrocentesis and injection are commonly employed in orthopedic practice, yet a paucity of literature supports currently described techniques. Two established techniques are described for stifle arthrocentesis in dogs; (1) stifle positioned slightly flexed, entering the skin from craniolateral or craniomedial and aiming for the intercondylar notch (LINC),[1] and (2) entering lateral to the patellar ligament and advancing proximally under the patella (INFRA).[6] Cadaveric models have been used to assess arthrocentesis teaching methods, but no studies have evaluated the accuracy or safety of different techniques in canine models.[7,8]

Iatrogenic articular cartilage injury (IACI) is a known complication of arthrocentesis and arthroscopy in human and veterinary medicine.[9] A recent publication revealed six out of 27 elbows had IACI following placement of a needle for arthroscopy.[10] Therapeutic joint injections reportedly carry a low risk of major adverse effects, yet the effect of potential iatrogenic damage to intra-articular structures on long-term joint health has not been evaluated in dogs.[3] Iatrogenic cartilage injury can vary in severity, ranging from minor surface damage to more extensive defects or tears. Hyaline cartilage is avascular, with limited regenerative capabilities.[11] Recent research indicates that even partial thickness hyaline cartilage defects can contribute to the development of osteoarthritis in the canine stifle, underscoring the significance of preventing even minor iatrogenic damage.[11–13]

In humans, various techniques for knee arthrocentesis have been evaluated in cadaveric models, assessing accuracy (number of attempts and repositions) and safety via assessment of iatrogenic articular cartilage injury (IACI), with suprapatellar approaches now preferred.[14,15] Infrapatellar techniques are not performed frequently in humans due to interference with the fat pad limiting the ability to acquire joint fluid, along with the risk of IACI and damage to vital intra-articular structures.[16,17] In people, the modified anterolateral bent knee portal (equivalent of LINC in dogs) has been shown to be an effective, accurate, and equivalent to the standard lateral midpatellar portal for intra-articular injection of the knee.[18] However, placement of the needle within the cruciate ligaments, menisci and injections into Hoffa's fat pad are reported limitations to this technique.[14,17]

The objectives of this study were (1) to determine which techniques are in use in clinical practice for stifle arthrocentesis in dogs, (2) to assess two established techniques for stifle arthrocentesis for accuracy and safety in a canine cadaveric model, and (3) to assess two novel suprapatellar approaches for stifle arthrocentesis in a canine cadaveric model for feasibility, accuracy and safety.

Based on clinical experience and the narrow anatomical space through which the needle must pass during INFRA, we hypothesized that INFRA would demonstrate a high rate of IACI compared to LINC in a canine cadaveric model. Based on human medicine literature demonstrating superior accuracy and safety of suprapatellar approaches,[14,15] we further hypothesized that novel suprapatellar approaches would be feasible, accurate and safe in a canine cadaveric model.

2 | MATERIALS AND METHODS

2.1 | Electronic survey

To ensure the clinical significance of the study design, a concise electronic survey was designed utilizing commercially available software (SurveyMonkey Inc., San Mateo, California) and distributed to members of the Veterinary

Arthrology Advancement Association listserv asking for voluntary participation with no incentives provided, regarding their preferred technique for stifle arthrocentesis in dogs. Answers and participation data were anonymized. Institutional ethical approval was obtained. Responses were included in the analysis if the survey was completed within a predefined period (30 days). Respondents were asked to select their routine technique, along with their preferred needle size. A free text area allowed respondents to type in any alternative techniques or modifications.

2.2 | Specimen collection and preparation

A total of 16 donated, small- to large-breed adult canine cadavers weighing 9–47 kg (median 32 kg) were collected following euthanasia for reasons unrelated to this study, with owner consent for research at our institution. The operator routinely used LINC and INFRA interchangeably in clinical practice prior to conducting this study. Before commencing data collection, a pilot study using two dogs was performed, allowing practice on two stifles for each of the new techniques (SUPRA and POUCH). Cadaveric specimens were stored at -20°C and thawed to room temperature for 48 h prior to testing. To ensure fidelity to a clinical scenario, the hindlimbs were not removed from the cadaver. Each hindlimb ($n = 32$) was identified by a number and randomly assigned to a group (LINC, INFRA, SUPRA, POUCH, $n = 8$ in each group).

Preprocedural craniocaudal and mediolateral radiographic projections were obtained of each stifle. Limbs were to be excluded if any significant osteoarthritis, trauma or deformity was noted radiographically.

The cadavers were placed in lateral recumbency with the procedural leg uppermost. A 10 cm x 10 cm patch of hair was clipped over the cranial aspect of each stifle. The stifles were held in a neutral/partially-flexed (LINC, INFRA) or neutral/slightly extended position (SUPRA, POUCH) depending on technique. All procedures were performed by a single right-handed operator, board-certified in small animal surgery and canine sports medicine, experienced in stifle arthrocentesis and injection (LCC).

2.3 | Injection techniques

Based on the results of the electronic survey, a 21 gauge, 38 mm (1.5 inch) hypodermic needle attached to a 3 mL syringe was used for all injections.

Lateral intercondylar notch technique (LINC); (Figures 1C and 2A): With the stifle positioned slightly flexed, the needle is inserted through the skin lateral to the patellar ligament, midway between the patella and tibial tuberosity and advanced towards the intercondylar notch in a cranio-lateral to caudo-medial direction.[1]

Lateral infrapatellar (INFRA) technique (Figures 1D and 2B): With the stifle positioned slightly extended, the needle is inserted through the skin lateral to the patellar ligament, midway between the patella and tibial tuberosity, and advanced proximally under the patella into the femoropatellar joint compartment.[6]

Lateral supratrochlear (SUPRA) technique (Figures 1E and 2C): With the stifle positioned slightly extended, the needle is inserted into the skin at the proximolateral border of the patella and aimed at 45° from horizontal, and directed into the suprapatellar bursa.[17]

Lateral femoropatellar pouch (POUCH) technique (Figures 1F and 2D): With the stifle slightly extended, the needle enters the skin at the level of the proximal patella, 1 cm lateral to the lateral aspect of the patella, and is directed distally parallel to the trochlear ridge into the lateral femoropatellar joint pouch.[19]

A "one needle two syringe" technique was used.[20] Once the needle was believed to be within the articular space, the syringe was aspirated to assess for the presence of synovial fluid. If synovial fluid was obtained it was recorded. If synovial fluid was not obtained, the operator decided whether to reposition or re-attempt or continue with synovial injection if they felt they were within the joint space, in spite of the lack of synovial fluid. For each technique, the number of repositions and attempts required to inject the stifle was recorded. A new attempt was defined as removing the needle from the skin before re-entering the skin. A reposition was defined as adjusting the position of the needle without removing it from the skin. The operator was allowed an unlimited number of attempts and repositions.

When the operator perceived the needle was within the joint, the syringe was removed from the needle hub and the joint was injected with a prefilled syringe containing room temperature iodinated contrast material (Omipaque 300 mg; GE Healthcare), as previously described for stifle arthrography (0.3 mL/cm of the medial to lateral thickness of the joint).[21] Passive range of motion for 20 cycles was performed to evenly distribute intra-articular contrast material.

2.4 | Post-procedural radiographic evaluation

Following the procedure, orthogonal radiographic projections were taken of each stifle to assess for accuracy using

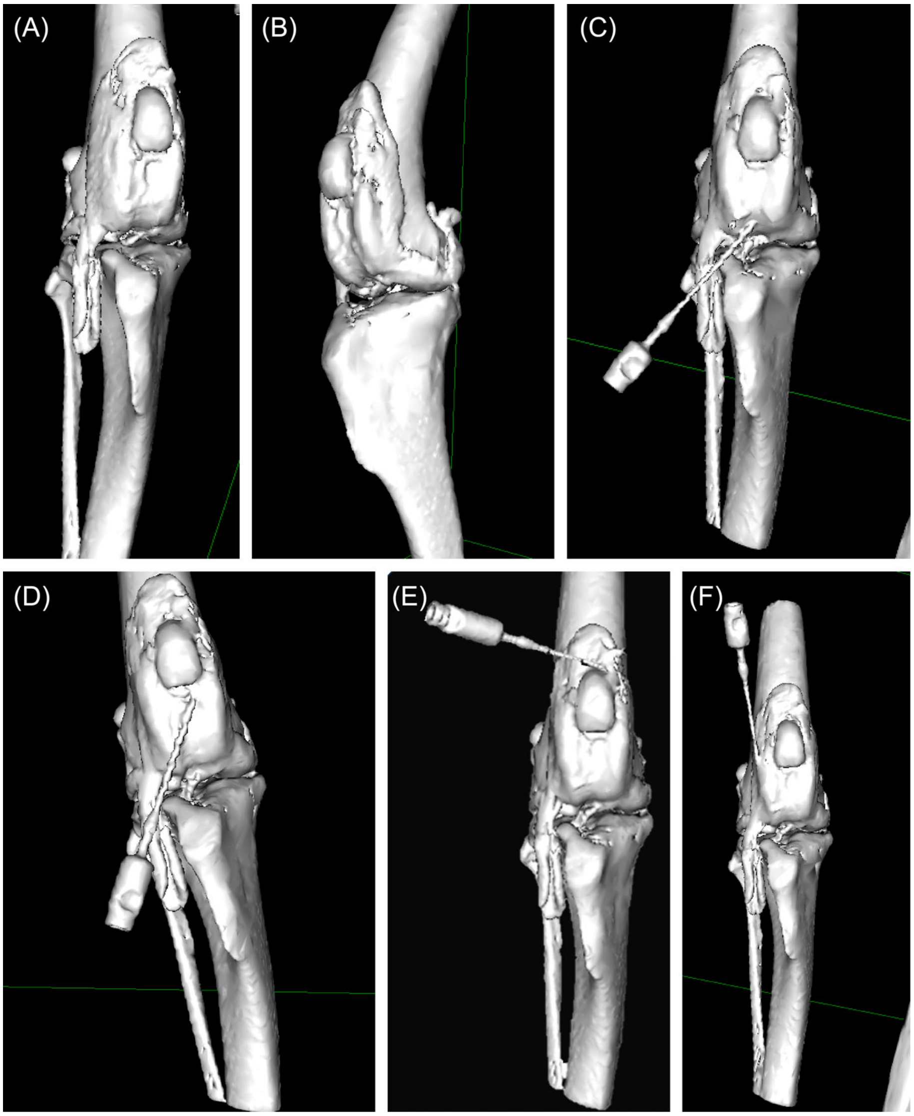

FIGURE 1 Computed tomography (CT) arthrography of canine stifle joint compartments (A, B) and arthrocentesis procedures. (C) Lateral intercondylar notch, (LINC). (D) Lateral infrapatellar (INFRA). (E) Lateral suprapatellar (SUPRA). (F) Proximal lateral parapatellar (POUCH).

arthrography. A separate blinded board certified surgeon (TPM) graded the anonymized radiographs for accuracy. The radiographs were given a score of 1 (completely accurate, all contrast medium within the joint), 2 (partially accurate, contrast within the joint and contrast in the periarticular tissues), or 3 (not accurate, no contrast within the joint). (Figure 3).[22,23]

2.5 | Post-procedural cartilage examination

Following radiographic evaluation, the stifles were carefully dissected and disarticulated via a medial approach. Post-procedural gross cartilage examination was performed by an independent operator, blinded to procedure (BMC). Each joint was photographed using a digital camera before and after India ink staining. The presence and location of native cartilage injury was documented and scored using the modified Outerbridge scale.[24,25] Native lesions were differentiated from IACI by their diffuse cobblestone appearance versus the sharp linear appearance of IACI.[26,27] An India ink assay was performed to assess for IACI.[27] India ink was applied to all articular surfaces and rinsed with water after 60 s. IACI was defined as sharply delineated linear or punctate lesions with India ink stain uptake.[27] Total IACI number, lesion location, length and width were measured directly on the joint surface using a medical calipers, and the surface area of IACI lesions calculated ($area = length \times width$). As the cadavers had been through a freeze–thaw cycle, histology for quantifying lesion depth was not performed.[28] Lesion depth was characterized as partial- or full-thickness depending on whether subchondral bone was exposed. IACI locations were identified as medial femoral condyle, lateral femoral condyle, intercondylar notch, trochlear groove, or non-weightbearing cartilage.

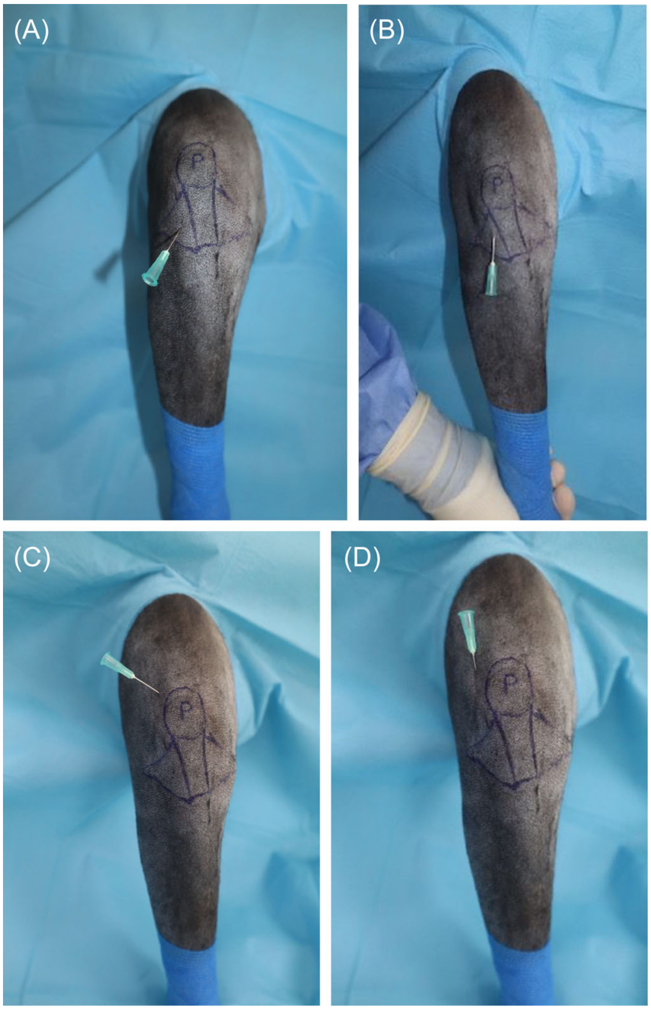

FIGURE 2 Right stifle of a cadaver in left lateral recumbency with procedural leg uppermost. Techniques for stifle arthrocentesis and injections. (A) Lateral intercondylar notch (LINC). (B) Lateral infrapatellar (INFRA). (C) Lateral suprapatellar (SUPRA). (D) Proximal lateral parapatellar (POUCH).

2.6 | Statistical analysis

Data were analyzed using R statistical software (version 4.0.5; R Core Team, Vienna, Austria). Categorical data were checked for spurious observations and summarized with counts, proportions, percents and tables. Group balance on gender, breed, and weight was checked by inspection of summary statistics for clinically relevant differences. Omnibus tests (Fisher exact tests for categorical outcomes, or Wilcoxon rank-sum tests for continuous outcomes) were used to determine overall statistical differences in surgical techniques. Statistical significance for the omnibus tests was set at $p < .05$. When an omnibus test had $p < .05$, post hoc Bonferroni-corrected pairwise statistical tests were used. Statistical significance for the post hoc tests under the correction was $p < .0083$, to account for type I error inflation.[29,30]

3 | RESULTS

3.1 | Survey results

A total of 40 surgeons responded to the email survey. Survey respondents preferred LINC (35/40, 87.5%, either lateral or medial entry) for stifle arthrocentesis, with the remaining respondents preferring INFRA (5/40, 12.5%). No other techniques were reported. Needle size ranged from 18 to 25 gauge; respondents predominantly used 20–22 gauge needles (30/40, 75%), with 21 gauge being most common (14/40, 34%), followed by 20 gauge (11/40, 27%), 22 gauge (6/40, 14%), 23 gauge (6/40, 14%), 18 gauge (3/40, 8%) and 25 gauge (1/40, 3%).

3.2 | Ex vivo outcomes

3.2.1 | Cadaveric specimens

Seven were entire males, five entire females, three neutered males and one neutered female. Breeds included two Wheaten Terriers, two German Shepherds, three mixed breeds and one of each of the following: Cavalier King Charles Spaniel, Rottweiler, Greyhound, Springer Spaniel, Labrador Retriever, Malamute, Pitbull, Lurcher, and Golden Retriever. No limbs were excluded from the study based on the preprocedural radiographs.

3.2.2 | Repositions, attempts and synovial fluid

The number of attempts (needle removed and reinserted) did not differ between techniques ($p = .6$). Needle repositions differed between techniques, with SUPRA (5/8, 63% stifles required two or more repositions) and INFRA (8/8, 100% stifles) requiring more repositions than LINC, where most stifles (7/8, 88%) were performed with no repositions (Table 1) ($p = .001$). Synovial fluid was obtained in 3/8 (38%) (POUCH, LINC), 4/8 (50%) (INFRA) and 5/8 (63%) (SUPRA) of stifles. Synovial fluid acquisition did not differ between techniques ($p > .9$).

3.2.3 | Accuracy

All techniques for stifle arthrocentesis were fully accurate in all 32 limbs based on stifle arthrography, with

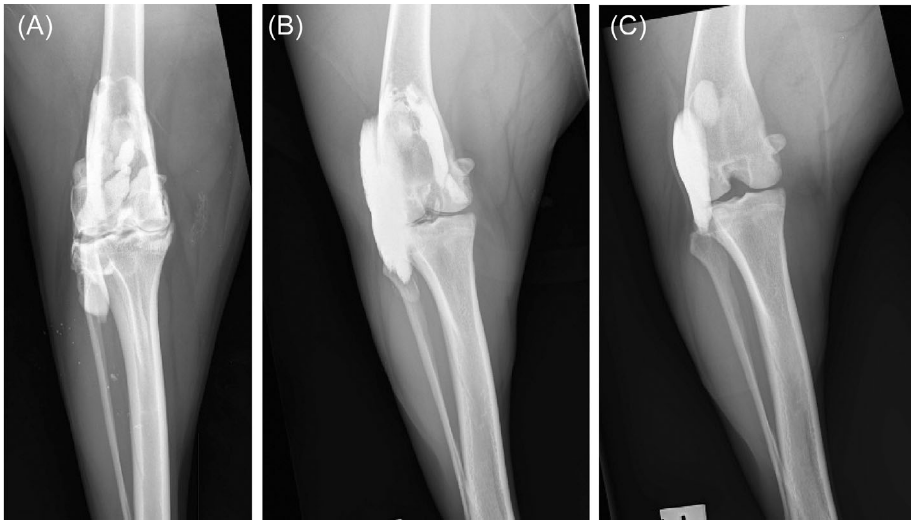

FIGURE 3 Craniocaudal stifle radiographs of post-procedural stifle arthrograms. (A) Score of 1, completely accurate. (B) Score of 2, partially accurate. (C) Score of 3, not accurate.

TABLE 1 Sum of overall attempts, repositions and acquisition of synovial fluid.

	LINC	INFRA	SUPRA	POUCH	*p*-value
Attempts	8	10	9	8	.6
Repositions (sum)	1	9	12	7	.001
0	7	0	2	3	
1	1	7	1	3	
2	0	1	4	2	
3	0	0	1	0	
Synovial fluid acquired	3	4	5	3	.9

Abbreviations: INFRA, lateral infrapatellar; LINC, lateral intercondylar notch; POUCH, proximal lateral parapatellar; SUPRA, lateral suprapatellar.

TABLE 2 Accuracy scores based on stifle arthrography.

Score	LINC	INFRA	SUPRA	POUCH
1	8	8	8	8
2	0	0	0	0
3	0	0	0	0

Abbreviations: INFRA, lateral infrapatellar; LINC, lateral intercondylar notch; POUCH, proximal lateral parapatellar; SUPRA, lateral suprapatellar.

no contrast identified in the periarticular tissues (Table 2) ($p > .9$).

3.2.4 | Iatrogenic articular cartilage injury

INFRA produced the highest incidence of IACI (6/8, 75% of stifles). POUCH produced the second highest incidence of IACI (5/8, 63%). LINC and SUPRA produced no IACI (0/8, 0% for both techniques) ($p < .001$). INFRA lesions frequently exceeded 10 mm^2 in area (3/6, 50%), with lesions ranging from 1 to 12 mm^2. POUCH lesions did not exceed 10 mm^2 ($p = .043$) (Table 3). INFRA produced full thickness IACI in 2/6 (33%) of cases ($p = .05$), and all but one IACI was located on weightbearing articular cartilage (5/6, 83%) (Table 3, Figure 4) ($p = .041$). POUCH produced no full-thickness lesions (0/5, 0%), and all IACI occurred on non-weightbearing articular cartilage (5/5, 100%) ($p = .041$) (Table 4).

4 | DISCUSSION

In this study of cadaveric canine stifles, all techniques for stifle arthrocentesis and injection were accurate; however, techniques differed with regards to safety. Survey respondents performed stifle arthrocentesis via the intercondylar notch approach most commonly (LINC) (35/40, 87.5%). This intercondylar approach was safe with regard to IACI in this model; however, assessing intra-articular soft tissue structures such as the cruciate ligament and menisci that may be damaged by this approach was beyond the scope of this study. The infrapatellar technique (INFRA) used by survey participants (5/40, 12.5%) carried a high risk of IACI on the trochlear groove (6/8, 75%), with lesions frequently full-thickness (2/6, 33%) and longer than 10 mm (3/6, 50%). The two novel suprapatellar techniques were feasible, accurate and safe.

IACI	LINC	INFRA	SUPRA	POUCH	*p*-value
Cartilage injury	0	6	0	5	<.001
Average area (mm^2)	0	11	0	7	.043
Lesion depth					.5
Partial thickness	0	4	0	5	
Full thickness	0	2	0	0	

TABLE 3 Incidence, size and thickness of iatrogenic articular cartilage injury.

Abbreviations: IACI, iatrogenic articular cartilage injury; INFRA, lateral infrapatellar; LINC, lateral intercondylar notch; POUCH, proximal lateral parapatellar; SUPRA, lateral suprapatellar.

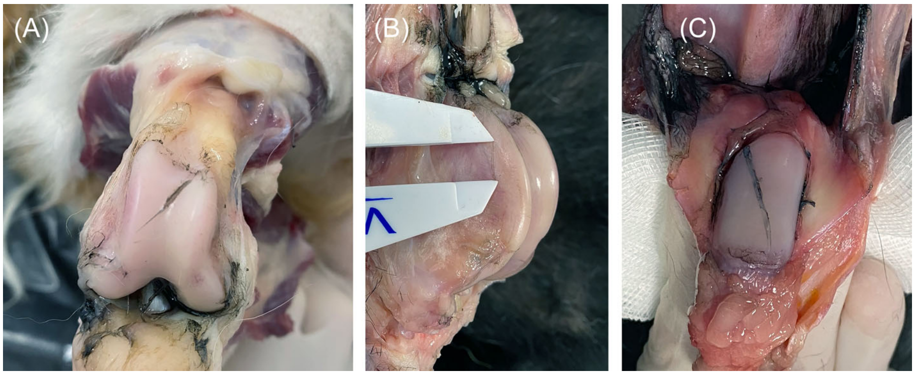

FIGURE 4 Iatrogenic articular cartilage injury (IACI) location after India ink staining. (A) Trochlear ridge. (B) Lateral to trochlear ridge. (C) Articular surface of patella.

Failed arthrocentesis attempts can lead to misdiagnosis, while failure of intra-articular delivery of therapeutic agents can result in diminished therapeutic impact or post-procedural pain.[31,32] In humans, landmark-based knee arthrocentesis and injection has reported accuracy rates of 27%–93%, depending on level of effusion and operator experience.[14,31,33,34] The accuracy rate of 100% (32/32 stifles) for all techniques for stifle injection as determined by stifle arthrography was a surprising result in this study, particularly as all techniques were performed using landmark-based approaches, relying solely on anatomical landmarks. All techniques were performed by a single very experienced operator in stifle arthrocentesis and arthroscopy. These results may not be reproducible by inexperienced or less experienced operators. While studies have evaluated cadaveric models for teaching stifle arthrocentesis, accuracy and safety were not evaluated in these studies, and the learning curve for stifle arthrocentesis is unknown.[7,8]

Synovial fluid was successfully aspirated in only 15/32 (47%) of stifles in this study even though contrast arthrograms showed the needle was positioned within the joint spaces in all stifles. The presence of synovial fluid was independent of technique, and was unrelated to IACI. Even if the needle is visualized entering the joint cavity accurately, it can be difficult to obtain joint fluid if synovial tissue, or Hoffa's fat pad occlude the needle tip. Cadaveric specimens that have been stored frozen and subsequently thawed contain little to no joint fluid.[7] In practice, stifle arthrocentesis is usually performed on an effused joint. We elected not to use an effused stifle model in this study due to the potential risk of IACI during introduction of fluid which would have complicated subsequent assessment of safety. In humans, the position of the knee during arthrocentesis has also been shown to affect the volume of joint fluid obtained with more joint fluid being aspirated from patients in the supine position (extended knee) than from patients in a sitting (flexed knee) position.[35] Further studies should assess the acquisition of synovial fluid via the various techniques in an effused stifle model and with the limb in different positions.

An increased number of attempts (withdrawing the needle from the skin and inserting a new needle), could increase the risk of iatrogenic contamination and septic arthritis.[36] The number of attempts did not differ between techniques; however, needle repositions differed, with a greater number of repositions required in SUPRA and INFRA techniques. This finding is difficult to interpret in light of variable acquisition of joint fluid in our model. In our study, the operator may have redirected more times due to a lack or small amount of aspirated fluid which the operator would usually use to confirm correct placement within the joint at specific locations.[8]

Techniques for stifle arthrocentesis differed significantly in terms of safety, as assessed in this study by IACI. Damage to articular cartilage has been demonstrated to alter collagen production, compromise matrix integrity, and disrupt cellular metabolism in cartilage of diarthrodial joints.[13] Small scrapes with arthroscopic instruments, or needles during arthrocentesis which

TABLE 4 Location of iatrogenic articular cartilage injury.

Location	LINC	INFRA	SUPRA	POUCH
Patella	0	3	0	0
Lateral trochlear ridge	0	1	0	5
Trochlear groove	0	1	0	0
Lateral to trochlear ridge	0	1	0	0

Abbreviations: INFRA, lateral infrapatellar; LINC, lateral intercondylar notch; POUCH, proximal lateral parapatellar; SUPRA, lateral suprapatellar.

commonly occur during practice, are not benign.[13] The long-term effects of small hyaline cartilage lesions are unknown; however, partial-thickness cartilage defects on the femoral articular cartilage in the canine stifle create a reliable and reproducible model of acute and progressive stifle osteoarthritis, known as the groove model of osteoarthritis.[12] As canine articular cartilage lacks significant regenerative capabilities, all potential for IACI should be reduced where possible.[11,27,37]

The intercondylar notch approach (LINC) was utilized in a clinical scenario by the overwhelming majority of respondents to our survey (35/40, 87.5%). In our cadaveric model, LINC was accurate (8/8, 100%) and safe (0/8, 0% IACI). This approach is analogous to the modified anterolateral or anteriomedial approach in humans which is used when the knee cannot be extended. However, acquiring synovial fluid with this approach can be challenging, and placement of the needle within the cruciate ligaments, menisci and extraarticular injections into Hoffa's fat pad is not uncommon.[14,16,38,39] A prospective study involving human knees injected with dilute methylene blue prior to knee arthroscopy found that the modified anterolateral/medial technique, may not be reliable for routine low-volume knee injections, with intra-articular delivery in less than half of the cases, and a high incidence of soft-tissue infiltration.[40] Our study did not assess potential damage to other intra-articular structures, such as cruciate ligaments and menisci, or the occurrence of soft tissue infiltration with the LINC technique.

The infrapatellar approach (INFRA) used routinely by survey respondents (5/40, 12.5%) proved to be accurate (8/8, 100%) but required significantly more needle repositions than POUCH and LINC. If a larger sample size were to be utilized, a higher number of attempts may also have become statistically significant. Most importantly, the INFRA technique produced a high incidence and severity of IACI (6/8, 75%) compared to other methods. In human medicine, infrapatellar approaches are not commonly utilized due to challenges in obtaining synovial fluid and the increased risk of IACI.[14,16] Our findings support avoiding this approach in veterinary practice given the combination of technical difficulty and substantial risk of cartilage damage, particularly full-thickness lesions that could have long-term clinical consequences.

The novel suprapatellar approach (SUPRA) was accurate (8/8, 100%), with no evidence of IACI (0/8, 0%), consistent with the results reported in people.[14,16,17,39,40] The SUPRA technique had the highest number of repositions in this study; however, given that it was the only technique not previously performed, in any form, this outcome may be expected due to learning curve. Based on the results of this study, we have successfully progressed to use this technique in effused clinical cases.

The second novel suprapatellar approach was based on the use of a stifle arthroscopy egress portal. This portal, typically employed by experienced veterinary arthroscopists for the placement of an outflow cannula, was adapted for the purpose of this technique.[41] A variation of this technique was reported by Clements et al.; however, their approach was from a distal location rather than suprapatellar.[42] In the present cadaveric study, the POUCH technique was accurate (8/8100%). However, IACI was observed in 5/8 (63%) stifles. Despite this relatively high incidence of IACI, all IACI were found lateral to the trochlear groove, on non-weightbearing articular cartilage and were partial thickness (0/5, 0% full thickness). This prompts further consideration of the clinical relevance of IACI in these areas. Damage to non-weightbearing articular cartilage could incite pain, synovitis and osteoarthritis similar to the donor site morbidity observed in osteochondral autograft transfer (OATS) procedures.[43] However, it is expected that such damage would have significantly less clinical impact compared to lesions affecting weightbearing areas. We have yet to use this technique in clinical effused stifles as it warrants further investigation.

While performing this study we noted that the direction of needle bevel could be strategically utilized to minimize the risk of cartilage injury. Notably, all instances of IACI in the POUCH technique occurred on the lateral aspect of the trochlear groove (5/5, 100%). By positioning the bevel facing the bone, the needle is more likely to travel in a controlled and direct path, allowing it to more accurately navigate through the joint space while minimizing damage to the articular cartilage. This technique ensures that the needle enters the targeted area with precision, thus reducing the potential for iatrogenic damage, which could otherwise compromise the cartilage and lead to adverse clinical outcomes. The use of bevel direction for minimizing cartilage injury is well-documented in human medicine, where similar techniques have been employed successfully to reduce the risk of joint trauma during procedures such as arthrocentesis and arthroscopy.[44] Changing bevel direction in the INFRA approach is likely to only change the surface affected by IACI from the trochlear groove to the patella, which is likely of little advantage.

Ultrasound-guided knee injections have been shown to be more accurate for every needle position in humans when compared to landmark-based injections.[45] Furthermore patient outcomes have been improved with ultrasound guidance, with significantly reduced procedural pain, greater aspirated fluid volume, greater accuracy and a greater percentage of successful diagnostic arthrocentesis and greater response to corticosteroid injections.[20,46,47] In simulated knee arthrocentesis, ultrasound-guided techniques increased first-attempt success over landmark-based techniques among medical students, most evident for arthrocentesis of smaller volume effusions.[48] Future veterinary studies should investigate whether image- guided injections, performed using ultrasonography or nanoscopy, influence outcomes, safety and accuracy in dogs.

The limitations of this study are inherent to a cadaveric study. Articular cartilage is more susceptible to IACI after a single freeze–thaw and we were unable to evaluate the depth of IACI.[28] We used one needle and syringe size, selected based on the results of our survey. All procedures were performed by a single experienced operator and do not account for a learning curve. A further limitation of this model is the lack of reliable acquisition of joint fluid, as cadaveric specimens that have been stored frozen and subsequently thawed contain little to no joint fluid.[7] We elected not to use an effused model, as described in the Johnson et al. study due to the risk of introducing IACI during fluid injection to mimic joint effusion. Additionally, gross examination of synovial fluid was not performed due to the cadaveric nature of this study. The data were analyzed using independent data statistical tests, although some data were repeated measures. The effect may have been to increase the false-positive rate; however, this may have been mitigated by the small sample size.[29,30] Future studies evaluating effect of stifle effusion, ultrasound-guidance and arthroscopic evaluation would be useful to further assess accuracy and safety. Additionally, future studies should evaluate the diagnostic utility of these techniques in clinical cases.

In conclusion, while all techniques were highly accurate for stifle injection (32/32, 100%), safety differed between techniques, with INFRA requiring more repositions and producing a higher risk for IACI (6/8, 75%). LINC was accurate and safe (0/8, 0% IACI). SUPRA was accurate and safe (0/8, 0% IACI) and warrants further investigation as a superior alternative to INFRA. POUCH was accurate but produced IACI on non-weightbearing cartilage (5/8, 63%) and requires further investigation before clinical use.

AUTHOR CONTRIBUTIONS

McClean B, MVB, MRCVS: Conceptualization, study design, data acquisition, manuscript preparation and revision. McNally TP, MVB, DACVS (Large Animal), DECVS, MRCVS: Study design, radiograph review, manuscript preparation and revision. Pozzi A, DMV, MS, DACVS (Small Animal), DECVS, DACVSMR, DECVSMR, PhD: Study design, manuscript revision. Evans R, PhD, PSTAT: Statistical analysis and interpretation, manuscript review. Cuddy LC, MVB, MS, DACVS (Small Animal), DECVS, DACVSMR, DECVSMR, MRCVS: Conceptualization, study design, data acquisition, manuscript preparation and revision. The authors would like to thank Roman Soto, DVM for his assistance in cadaver preparation and imaging.

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CONFLICT OF INTEREST STATEMENT

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

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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