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EXPERIMENTAL LAB RESEARCH

WILEY

Evaluation of iatrogenic articular cartilage injury associated with arthroscopic exploration of the canine elbow

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Abstract

Objective: To quantify the incidence, extent, and distribution of iatrogenic articular cartilage injury (IACI) during canine elbow arthroscopy and to investigate the effect of arthroscope size on IACI.

Study design: Experimental study.

Sample population: A total of 72 elbows from fresh frozen large breed canine cadavers.

Methods: Elbows were alternately assigned to nine groups consisting of different combinations of arthroscope size (1.9, 2.4, 2.7 mm) and surgeon experience (novice, intermediate, advanced). Routine arthroscopic exploration of the elbow was performed. Number of obturator insertions and procedure time were recorded. Joints were disarticulated and stained with India ink. The incidence and total surface area of IACI were determined. A linear mixed model was used to evaluate the effect of arthroscope size on IACI, procedure time, and number of obturator insertions.

Results: The incidence of IACI was 100% with a median affected surface area of 10.6 mm^2 (interquartile range [IQR]: 6.4–15.6). Median IACI was lowest for the 2.4 mm arthroscope, which was significantly less than the 2.7 mm arthroscope ($p = .006$). There were no significant differences in number of obturator insertions per arthroscope size ($p = .96$). Procedure time was significantly longer with the 1.9 mm than the 2.7 mm arthroscope ($p = .03$).

Conclusion: Routine arthroscopic joint exploration resulted in IACI in 100% of elbows. The 2.4 mm arthroscope was associated with the lowest extent of IACI.

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Abbreviations: ED, elbow dysplasia; IACI, iatrogenic articular cartilage injury; MCD, medial coronoid disease.

Clinical significance: Surgeons should be aware that IACI occurs routinely during canine elbow arthroscopy. Further research is warranted to investigate clinical significance and to develop methods that minimize IACI during canine elbow arthroscopy.

1 | INTRODUCTION

Arthroscopy of the canine elbow is frequently performed for the diagnostic evaluation and treatment of lameness secondary to elbow dysplasia (ED). As a common cause of forelimb lameness in large breed dogs, ED encompasses a variety of conditions, including medial coronoid disease (MCD), ununited anconeal process, osteochondrosis, and joint incongruity.[1] Arthroscopy can be a valuable diagnostic tool for the assessment of ED by assisting in the characterization of its different components, including the extent and severity of articular cartilage damage.[2–4] These findings may serve as a useful guide for the surgeon, informing the selection of appropriate treatment strategies, such as the consideration of load-shifting procedures in cases with isolated medial compartment disease, and facilitating a prediction of long-term prognosis through the evaluation of cartilage wear. Another proposed advantage of arthroscopy for the evaluation of ED is that it affords the opportunity for direct therapeutic intervention, most commonly involving the treatment of MCD via fragment removal and abrasion arthroplasty.[5,6]

While arthroscopy serves as a valuable, minimally invasive tool for the diagnosis and treatment of MCD, it is important to acknowledge the continued controversy regarding the efficacy of surgical versus non-surgical management of MCD, with several more recent studies indicating no difference in long-term clinical outcomes.[7–9] A meta-analysis comparing medical management, medial arthrotomy, and arthroscopy found that arthroscopy was superior to medical management; however, the authors note the supporting evidence of the studies was weak.[10] One of the main challenges in achieving effective ED treatment stems from the considerable variation in associated joint pathology, alongside a limited understanding of how these factors interrelate with clinical disease. As a result, recommendations to perform diagnostic, therapeutic and/or prophylactic elbow joint arthroscopy remain highly variable and debatable among surgeons.

In light of the ongoing controversies surrounding the optimal management of ED, it is essential to recognize and mitigate the potential adverse effects of arthroscopy. Due to the highly congruent nature of the canine elbow joint, the risk of iatrogenic articular cartilage injury (IACI) and subsequent chondrocyte death are of particular concern.[11–14] Previous experimental studies have reported a wide range of IACI incidences associated with canine elbow arthroscopy, varying from 26% to 100%.[15–17] Notably, a 2.7 mm arthroscope was used in all of these studies, even though a 1.9 mm arthroscope is often selected for elbow arthroscopy due to the highly congruent nature of the joint.[18,19] In order to refine our understanding of canine elbow arthroscopy and enhance our management strategies for ED, there is a critical need for a thorough, objective evaluation of the IACI that occurs secondary to canine elbow arthroscopy and to investigate potential protective measures against IACI.

The objectives of this study were therefore (1) to quantify the incidence, extent, and distribution of IACI secondary to canine elbow arthroscopy and (2) to investigate the effects of arthroscope size on IACI. Our hypotheses were that the incidence of IACI would be 100% and that arthroscope size would be positively correlated with the extent of IACI.

2 | MATERIALS AND METHODS

2.1 | Study subjects

This study was approved by the Animal Care and Use Committee of the University of Georgia. Fresh frozen cadavers of adult large breed dogs (20–40 kg), euthanized for reasons unrelated to this study, were obtained for use. All cadavers were thawed for 48 h prior to arthroscopy. A total of 72 elbows were randomly assigned to nine different groups, based on arthroscope size (1.9, 2.4, 2.7 mm) and three surgeons with different levels of experience. These surgeons included a board certified surgeon (SB), who had performed >100 elbow arthroscopy procedures prior to initiation of the study, a board certified surgeon (VV), with <100 elbow arthroscopy procedures performed, and a surgical resident (AI), with 0 elbow arthroscopy procedures performed. Randomization was carefully managed to ensure that elbow joints belonging to the same dog were examined using an arthroscope of consistent size, yet were allocated to different surgeons.

2.2 | Arthroscopy

Arthroscopy was conducted with a high-definition arthroscopy system (Image1 S Connect II high-resolution

camera system, Karl Storz, Tuttlingen, Germany), employing a 1.9, 2.4, or 2.7 mm 30° forward-oblique arthroscope (Hopkins Forward-Oblique Telescope, Karl Storz, Tuttlingen, Germany), each accompanied by their respective blunt conical obturator and arthroscope sheath, with outer diameters of 2.5, 3.2, and 4.0 mm, respectively (arthroscope sheath, Karl Storz).

Dogs were positioned in dorsal recumbency and the medial aspect of the elbow joints were clipped. A padded fulcrum was placed under each elbow to enable joint distraction. Using a surgical assistant, the limb was positioned in a standing angle and both moderate traction and lateral pressure was applied to the distal antebrachium to open the medial elbow compartment.

Elbow arthroscopy was performed using standard medial portals as previously described.[20] An 18-gauge hypodermic needle was introduced into the joint at the arthroscope portal site, approximately 1 cm distal and slightly caudal to the medial epicondyle (Figure 1). Synovial fluid was aspirated to confirm appropriate placement within the joint. The joint space was subsequently insufflated with lactated Ringer's solution until moderate pressure was appreciated. The needle was removed, and a # 11 scalpel blade was used to make a small (0.5 cm) stab incision through the skin and superficial soft tissues. A blunt conical obturator was inserted into the respective arthroscope cannula and placed through the incision into the joint. The obturator was removed and replaced with the arthroscope to verify accurate positioning within the joint. Fluid ingress was initiated and controlled using a pressure bag, with pressures maintained at 60–75 mmHg. Prior to performing joint exploration, an egress portal was established at the caudal aspect of the joint using a 1.5-inch-long, 18-gauge hypodermic needle inserted adjacent to the medial surface of the olecranon process (Figure 1). Systematic exploration of the joint was performed, including visualization of the following structures: anconeus, ulnar trochlear notch, lateral coronoid, central medial coronoid process, cranial medial coronoid process, radial head, synovium, medial collateral ligament, cranial medial humeral condyle, central medial humeral condyle, and the axial region of the lateral humeral condyle. Following visual joint inspection, an instrument portal was established. Under direct arthroscopic visualization, an 18-gauge hypodermic needle was inserted into the joint approximately 1–2 cm cranial to the arthroscope portal (Figure 1). A #11 scalpel blade was then carefully inserted into the joint following the same trajectory as the needle and the instrument portal was enlarged using straight hemostatic forceps. To conclude arthroscopic exploration of the elbow joint, a right-angle blunt probe was inserted into the open instrument portal and used to palpate the articular surface of the medial coronoid process.

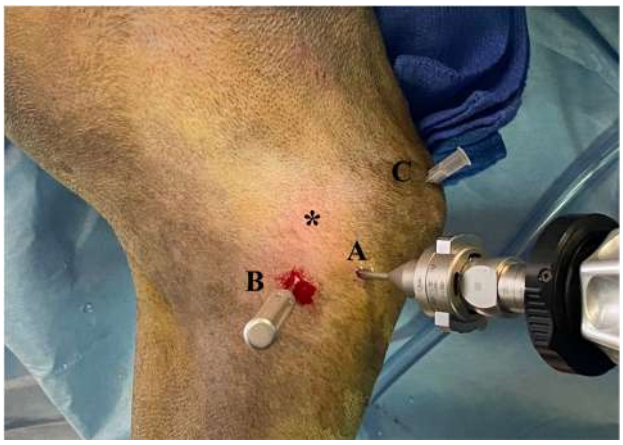

FIGURE 1 Photograph depicting the portal and egress locations on the medial aspect of the elbow, including arthroscope portal (A), instrument portal with blunt probe (B), and egress needle (C). The medial epicondyle is indicated with an asterisk (*). Cranial is to the left of the image.

Throughout each procedure, all visualized anatomic structures, including any observable joint pathology, were documented. Dogs with pre-existing elbow joint pathology were excluded from further analysis. The number of obturator insertions and procedure time were recorded, with procedure time defined as the time from joint insufflation to removal of the arthroscope. All arthroscopic procedures were video recorded to help correlate IACI lesions with specific surgical manipulations.

2.3 | Articular cartilage assessment

Prior to data collection, the disarticulation technique was refined on a series of separate cadaveric specimens to ensure no IACI occurred during joint dissection. For each test subject, the cubital joint was disarticulated immediately after arthroscopy and followed by an India ink assay of all articular surfaces. India ink does not penetrate intact articular cartilage, but will adhere to fibrillations in articular cartilage.[21] This selective staining highlights cartilage defects, allowing clear gross visualization of IACI lesions.[22,23] High-quality photographs were obtained of the following anatomic regions: cranial humeral condyle, central humeral condyle, radial head, medial aspect of the trochlear notch and medial coronoid process (Figure 2). A scientific ruler was positioned at the level of the articular surface to allow for image calibration.

The number of lesions were quantified per anatomic region, including the ulnar trochlear notch, medial coronoid process, humeral trochlea, capitulum, cranial

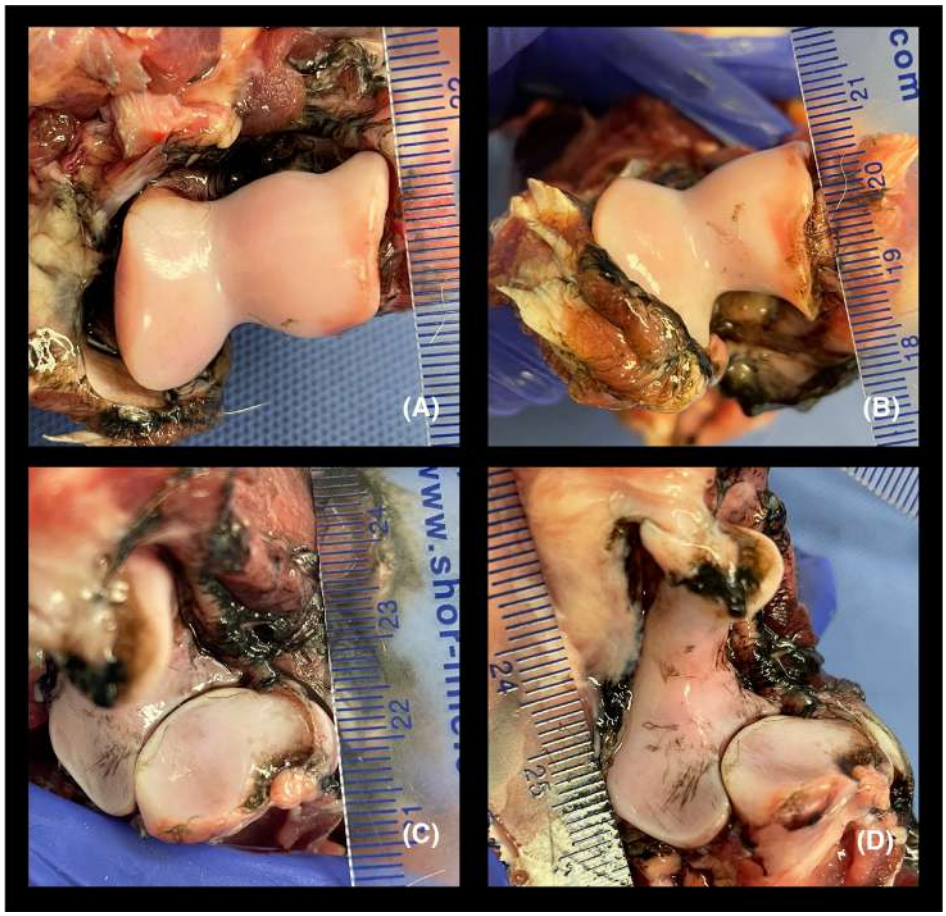

FIGURE 2 Standardized photographs of disarticulated joint surfaces following India ink assay: Cranial humeral condyle (A), central humeral condyle (B), radial head (C), and medial aspect of the trochlear notch and medial coronoid process (D).

humeral condyle, and radial head. Lesions were subclassified as either punctate lesions, linear scratches, abrasions, or tracts. Punctate lesions and linear scratches were defined as narrow (<0.5 mm) round or linear defects associated with the use of hypodermic needles. Abrasions and tracts were defined as wider (>0.5 mm) irregularly shaped or linear defects associated with the use of obturators. The incidence and extent of IACI was quantified by a single investigator (AI) using an image processing software program (ImageJ1.53 k, National Institutes of Health, USA). Images were calibrated using the scientific ruler embedded within each photograph. The surface area of each IACI lesion was subsequently measured, and the cumulative surface area encompassing all IACI lesions (total IACI) within each joint was calculated (Figure 3).

2.4 | Statistical analysis

Data analysis was performed by a statistician using statistical software (SAS 9.4, Cary, North Carolina). Due to the lack of data pertaining to IACI associated with canine elbow arthroscopy, a priori power analysis was not performed. Enrollment continued until 72 elbows without pre-existing pathology were obtained, ensuring the target sample size was maintained despite exclusions. Based on the results of a sensitivity analysis, demonstrating significantly more IACI on day one compared to the remainder of the study, data collected on day one was excluded from analysis. The final dataset consisted of 60 elbows, with even distributions of arthroscope size and surgeon experience preserved. Numerical data was assessed for normality and summarized accordingly using descriptive statistics. Linear mixed models were used to analyze total IACI, procedure time, and number of obturator insertions. The model for each endpoint included a fixed factor of scope size and random intercepts for each dog and surgeon, and procedure time as a model covariate. Significance was set at a p-value of $< .05$. Intersurgeon standard deviations (SD) in total IACI and procedure times were calculated. A Spearman correlation analysis was performed to evaluate for potential learning effects within each surgeon over time.

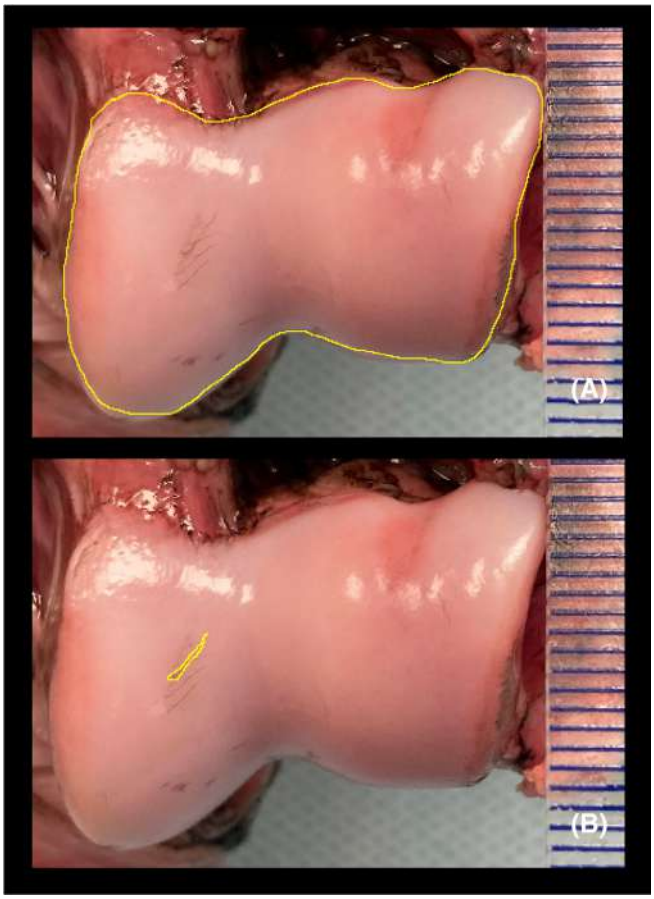

FIGURE 3 Photographs depicting measurement of the entire articular surface area (A) and measurement of an individual iatrogenic lesion (B) using an image processing software program.

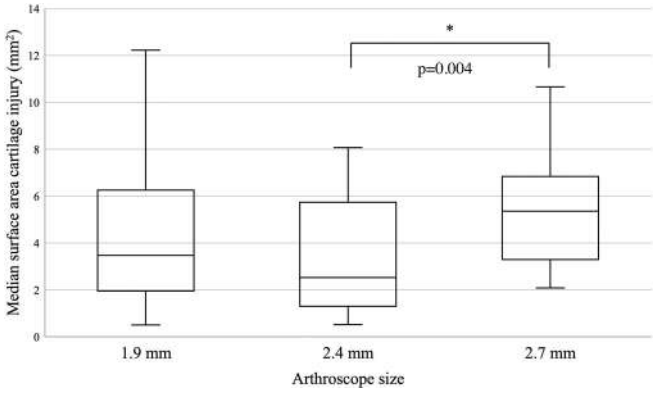

FIGURE 4 Box and whisker plot depicting the median surface area of iatrogenic articular cartilage injury in mm^2 (x axis) plotted against arthroscope size with interquartile ranges (y axis). The asterisk (*) indicates statistical significance with a *p*-value .004.

3 | RESULTS

The incidence of IACI was 100% with cartilage lesions identified in all joints. The overall median surface area of IACI was 10.6 mm^2 (interquartile range [IQR]: 6.4–15.6). The median surface area of IACI caused by the 1.9 mm, 2.4 mm and 2.7 mm arthroscopes was 8.6 mm^2 (IQR: 6–14.5), 5.7 mm^2 (IQR: 4.4–10.3) and 11.4 mm^2 (IQR: 10.4–14.1), respectively (Figure 4). The 2.4 mm arthroscope was associated with significantly less IACI compared to the 2.7 mm arthroscope ($p = .004$). There were no significant differences in IACI between the 1.9 mm and 2.4 mm ($p = .57$) or the 1.9 mm and 2.7 mm ($p = .06$) arthroscopes. The median number of IACI lesions per joint was eight (IQR 7–10). All IACI lesions were associated with establishment of the arthroscope portal and most commonly affected the ulnar trochlear notch (44%), followed by the humeral trochlea (26%) and capitulum (23%) (Table 1). No IACI lesions were associated with establishment of the instrument or egress portals. The majority of lesions (68.2%) were classified as linear scratches or punctate lesions and were associated with hypodermic needle use during joint insufflation. The remaining 31.8% of lesions were classified as abrasions or tracts and were associated with obturator insertion (Table 1). Median procedure times and number of obturator insertions were 5.6 min (IQR: 4.1–8.1) and one (IQR: 1–2) (Table 2). Procedure times were significantly longer with the 1.9 mm than the 2.7 mm arthroscope ($p = .03$). There were no significant differences in procedure time between the 1.9 and 2.4 mm ($p = .07$) or between the 2.4 and 2.7 mm ($p = .92$) arthroscope. There was a significant effect of procedure time on total IACI, with longer procedure times being associated with increased total IACI ($p = .04$). There were no significant differences in number of obturator insertions per arthroscope size ($p = .96$). The intersurgeon SD was 1.9 mm^2 for total IACI and 1.7 min for procedure time. No learning effects were detected using the Spearman's correlation analysis.

4 | DISCUSSION

This study provides important data regarding the incidence, extent, and distribution of IACI induced during arthroscopy of the canine elbow via standard medial portals. The incidence of IACI was 100%, confirming our first hypothesis. The ulnar trochlear notch and the humeral condyle were commonly affected, with IACI in these regions typically associated with insertion of either the hypodermic needle or the blunt obturator during establishment of the arthroscope portal. There was low variability in the extent of IACI between surgeons of differing levels of experience and no learning effects were detected. Overall IACI was not correlated with arthroscope size, and thus our second hypothesis was rejected.

Anatomic region	Percentage of IACI lesions	Number of punctate lesions and linear scratches	Number of abrasions and tracts
Ulnar trochlear notch	44%	158	100
Humeral trochlea	26%	122	29
Capitulum	23%	80	54
Cranial humeral condyle	3%	17	0
Radial head	3%	16	0
Medial coronoid process	0%	0	0

TABLE 1 Distribution and characterization of iatrogenic articular cartilage injuries.

	Procedure time (min)		Number of obturator insertions	
Arthroscope size	Median	Interquartile range	Median	Interquartile range
1.9 mm	6.9	2.9–21.2	1	1–2
2.4 mm	5.1	2.4–17.0	1	1–2
2.7 mm	5.3	2.3–11.0	1	1–2

TABLE 2 Median and interquartile ranges for procedure time and number of obturator insertions per arthroscope size.

The incidence of IACI documented in this study exceeds that reported in several previous reports.[15–17] It is important to note that the assessment of IACI in these previously published studies occurred subjectively, without the use of an India ink assay, and that the IACI lesions were not quantified. This could have resulted in an underestimation of both the incidence and severity of IACI. Similar concerns exist in human medicine, as recently demonstrated by Compton et al., who observed IACI in over 70% of surgeon-published instructional videos, all performed by experts in the field.[13] This incidence rate far exceeds the 7.9% IACI rate reported in a previous systematic review, indicating that the incidence of IACI in human arthroscopy is likely substantially underestimated.[13,24] Given the high incidence of IACI observed in the present study, the investigation of specific methods that can prevent or reduce IACI during canine elbow arthroscopy remains prudent.

Three surgeons of differing levels of experience were selected to participate in this study to capture the range of IACI that may occur during canine elbow arthroscopy. While surgeon experience has been correlated to the risk of IACI and subsequent hip surgery in human hip arthroscopy, the low number of participating surgeons in this study precluded us from evaluating the effect of surgeon experience on IACI.[25] That being said, the low variability in IACI between the surgeons and lack of learning effects observed in our study suggests that many surgeons likely induce IACI during canine elbow arthroscopy, regardless of their level of experience, and emphasizes the importance of other factors, such as surgical technique and instrumentation, in the occurrence of IACI.

In the present study, IACI was typically associated with insertion of either the hypodermic needle or the blunt obturator during establishment of the arthroscope portal. Joint insufflation was performed using an 18-gauge hypodermic needle inserted at the location of the arthroscope portal for all procedures. Using a smaller needle inserted at the egress site in the larger caudal joint space may help prevent associated IACI lesions and warrants evaluation in future studies.[15] Remarkably, there was no apparent correlation between arthroscope size and the extent of IACI. Despite the elbow being a highly congruent joint, where a larger arthroscope and cannula might be expected to cause greater IACI, the results did not consistently support this assumption. Specifically, while the 2.7 mm was associated with increased IACI compared to the 2.4 mm arthroscope, the 1.9 mm arthroscope did not result in significantly less IACI than either the 2.4 or 2.7 mm arthroscopes. Surprisingly, the median IACI caused by the 1.9 mm arthroscope was greater than that of the 2.4 mm arthroscope. Furthermore, the 1.9 mm demonstrated the widest range in IACI, indicating decreased consistency. These findings correlated with the subjective experiences of the participating surgeons, who reported greater difficulty entering the joint with the 2.7 mm obturator, and also perceived that the 1.9 mm arthroscope could occasionally be too easily manipulated within the joint, potentially leading to unintentional advancement towards the humeral condyle. Another

factor to consider is that due to its smaller field of view, the 1.9 mm arthroscope may require more manipulation to fully evaluate the joint, potentially increasing the risk of IACI. This increased need for manipulation likely also contributed to the longer procedure times observed with the 1.9 mm arthroscope. These results highlight the complexity of arthroscope selection. The selection of scope size is multifactorial and influenced by surgeon preference, patient size, the stage of disease, and/or procedural intent. While smaller arthroscopes tend to be preferred for smaller patients and diagnostic procedures, some surgeons may prefer the use of larger arthroscopes to facilitate joint treatment due to the wider field of view, which can enhance visualization and minimize instrument manipulation. These considerations emphasize the need for further studies to optimize scope selection and assess whether tailoring arthroscope size to individual patient and procedural requirements may reduce IACI while maintaining procedural efficacy.

Longer procedure times were associated with increased IACI in this study. Prolonged procedures may reflect challenges in joint navigation, either due to decreased visibility, limited joint space, or relative inexperience, all of which could impact precision or necessitate increased manipulations. This finding underscores the importance of refining arthroscopic techniques to improve procedural efficiency.

Additional methods to reduce IACI during elbow arthroscopy should be explored in future studies. Potential strategies include the use of smaller hypodermic needles, refinements in instrument design, and improvements in surgical technique or training. The use of silicone-guarded cannulas has previously been found to reduce the number and size of IACI lesions in canine stifle arthroscopy and may afford similar benefits for the canine elbow.[22] More recently, the use of needle arthroscopy systems has gained popularity in both human and veterinary orthopedics and has been demonstrated to result in less IACI and postoperative pain in humans.[26–29] The use of needle arthroscopy for exploration of the canine elbow has previously been evaluated in two separate studies, and was noted to result in IACI in 0% and 50% of elbows, respectively.[29,30] It is important to note, however, that the evaluation for IACI lesions in this study was conducted arthroscopically, which has previously been documented to have low sensitivity (30%).[23] This raises the possibility that the true incidence of IACI associated with needle arthroscopy may be underestimated, particularly for subtle or superficial lesions that may not be readily apparent during live arthroscopic evaluation.

Although the long-term clinical implications of arthroscopic-induced IACI remains unknown, the topic has garnered increasing attention in both human and veterinary medicine.[11–14,18,19,22,23,29–31] A recent landmark study demonstrated that even minor iatrogenic injuries caused by direct pressure with a blunt obturator, where the cartilage remained visibly intact, resulted in distinct zones of chondrocyte death.[13] The loss of chondrocytes has been well documented to disrupt cartilage homeostasis, leading to degradation of the extracellular matrix and progressive joint degeneration which is characteristic of osteoarthritis.[32,33] This is further supported by the canine groove model, during which partial thickness articular cartilage defects are created to provide a reliable and reproducible model of acute progressive stifle osteoarthritis.[34] The depth of IACI appears to play an important role, with lesions extending through the tidemark demonstrating limited healing characterized by fibrous tissue formation, while superficial lesions demonstrate partial repair with regenerative changes such as chondrocyte cloning and surface smoothing.[14] Therefore, it seems plausible that deeper IACI lesions in particular have the potential to contribute to long-term clinical morbidity. While further research is certainly required to understand the potential effects of IACI on long-term joint health and function, the quantification of IACI provided by this study offers a crucial starting point. As such, the findings of this study should not be interpreted as a deterrent to arthroscopy but rather as an opportunity to refine existing techniques and instrumentation to further minimize IACI while maintaining its diagnostic and therapeutic benefits.

The main limitations of the present study are those inherent to a cadaveric study. Cadaveric cartilage does not completely mimic the properties of in vivo articular cartilage and may be more susceptible to iatrogenic damage. Fresh frozen, single thaw cadavers were used to minimize the effects of natural post-mortem degradation and multiple freeze–thaw cycles on IACI. Only cadavers with grossly normal elbows were included in this study. Joints with pre-existing chondromalacia, as often encountered in a clinical scenario, could also have been more prone to iatrogenic damage. To minimize potential effects of joint size, we restricted our sample to large breed dogs, however, differences in body condition within this group resulted in a weight range of 20–40 kg. Variations in body size may still have been substantial enough to influence the results. Histopathology was not performed, which could have provided valuable information regarding IACI depth. Due to an inability to perform a priori power analysis, type 1 or 2 errors may have occurred. Lastly, although the surgical resident in the novice group had no prior independent live animal arthroscopy experience, prior exposure to arthroscopy was obtained as a surgical assistant and through a cadaveric training laboratory. These prior exposures likely facilitated their ability to

complete the arthroscopy tasks and may have influenced performance compared to a completely inexperienced operator.

In conclusion, the incidence of IACI that occurred during routine arthroscopic exploration of the canine elbow was 100%. The use of a 2.4 mm arthroscope was associated with less IACI than a 2.7 mm arthroscope in large breed dogs. Surgeons should be aware that IACI may commonly occur during canine elbow arthroscopy, regardless of surgeon experience. Further investigations are warranted to elucidate the clinical significance of IACI and to establish methods that reduce IACI during canine elbow arthroscopy.

AUTHOR CONTRIBUTIONS

Iodence AE, DACVS (Small Animal), DVM: Acquisition of data, analysis and interpretation of data, drafting the article, revising the article for intellectual content, final approval of the completed article. Verpaalen V, DVM, MS, DACVS (Small Animal): Conception and design, acquisition of data, analysis and interpretation of data, revising the article for intellectual content, final approval of the completed article. Hinson WD, DVM, MS, DACVS (Small Animal): Acquisition of data, analysis and interpretation of data, revising the article for intellectual content, final approval of the completed article. Budsberg SC, DVM, MS, DACVS: Acquisition of data, revising the article for intellectual content, final approval of the completed article.

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CONFLICT OF INTEREST STATEMENT

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

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