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Delays to fracture stabilization and the effect on postoperative outcomes: A retrospective cohort study of 211 canine humeral condylar fractures

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Abstract

Objective: To investigate the effect of surgical delay on radiographic and patient outcomes following canine humeral condylar fracture stabilization.

Study design: Retrospective observational cohort study.

Sample population: A total of 211humeral condylar fractures (204 dogs).

Methods: Time to surgery and clinical data were collected from the medical record. Immediate postoperative radiographs were reviewed for an intracondylar gap or articular step defect. Postoperative complications and short-term outcome data were collected with a minimum 28-day follow-up period. Multivariable logistic regression analysis modeled radiographic and patient outcomes.

Results: Fracture events occurring on Friday or Saturday were systematically associated with longer delays to surgery ($p < .001$). Increasing delays to surgery were associated with an increased risk of an intracondylar gap or articular step defect on immediate postoperative radiographs (adjusted OR = 3.86 per additional day, 95% CI: 2.04–7.29, $p < .001$). Presence of an intracondylar gap or articular step defect was associated with an increased risk of postoperative complications (adjusted OR = 5.92, 95% CI: 1.44–24.36, $p = .01$). Presence of an intracondylar gap or articular step defect was associated with an increased risk of a poorer short-term outcome (adjusted OR = 0.13, 95% CI: 0.04–0.42, $p = .001$). The presence of postoperative complications increased the risk of a poorer short-term outcome (adjusted OR = 0.38, 95% CI: 0.17–0.87, $p = .02$).

Conclusion: Delays to surgery are an important system-level factor influencing the accuracy of fracture reduction, postoperative complications, and short-term outcomes in canine humeral condylar fracture repair.

Clinical significance: System-level optimization may be an avenue for quality improvement in this patient population.

1 | INTRODUCTION

Humeral condylar fractures represent the most frequently encountered type of humeral fracture in dogs[1] and are among the most common articular fractures in small animal practice.[2] Fractures of the lateral part of the humeral condyle are most common with fractures of the medial part of the humeral condyle or Y-T fractures being less common.[3] Spaniel breeds and the French Bulldog are predisposed to humeral condylar fracture,[4] although underlying etiologies may differ between these breeds.[5,6]

As articular fractures compromise the integrity of the joint surface, anatomic reduction and rigid fixation are critical to minimize post-traumatic osteoarthritis and loss of function.[7,8] Despite anatomic reduction, some degree of progressive osteoarthritis is inevitable following humeral condylar fractures[9] with up to 57% of dogs experiencing long-term pain or lameness.[10,11]

Surgical repair may be performed via open or minimally invasive approaches.[12] Internal fixation is typically achieved using a transcondylar screw in conjunction with epicondylar bone plating and screws, epicondylar antirotational Kirschner wires, or an epicondylar bone screw.[4,11] Other techniques include the application of antirotational Kirschner wires as sole implants in skeletally immature dogs, and the use of a lateral epicondylar anatomic plates with a transcondylar screw.[13,14] Among studies, the type of transcondylar implant varies and cortical screws in lag or positional fashion, shaft screws, headless compression screws, and cannulated screws may be used.[14–16]

Reported postoperative complication rates range from 13.4% to 41.5%.[11,17–20] Risk factors for complications include prolonged surgery, non-anatomic reduction, Kirschner wire epicondylar fixation, and increased transcondylar screw angle.[4,11,18,19,21] The effect of implant selection is uncertain as there are some studies reporting no difference in complication rates between epicondylar plate and Kirschner wire fixation,[11,22] with epicondylar Kirschner wires suggested to be an appropriate choice of implants for skeletally immature dogs.[23] Apart from directly causing patient morbidity and increasing the costs of veterinary treatment, postoperative complications may be associated with poorer patient outcomes.[11]

In human traumatology, articular and juxta-articular fractures are recognized as time-sensitive conditions. In geriatric people, femoral head or neck fractures operated on within 48 h are associated with lower mortality and complication rates,[24] with recent evidence suggesting that surgery within 12 h may further optimize outcomes.[25] Early surgical management of juxta-articular humeral and radial fractures similarly reduces morbidity and improves outcomes.[26,27] These findings largely reflect the increased risk of systemic complications in elderly people undergoing fracture repair but show that surgical timing may have potential relevance. Although no studies have directly examined the impact of surgical delay on canine articular fractures, minimizing delay is generally considered best practice. Most dogs undergo fracture fixation within 3 days of injury, although a wide range of delays may occur for both medical and non-medical reasons.[19,28] Anecdotally, delayed attempts at open reduction and internal fixation of canine humeral condylar fractures are often more challenging, as early periarticular callus formation must be disrupted to achieve anatomic reduction.[8] Furthermore, delayed intervention may mean that a minimally invasive approach is no longer possible.

Given the evidence from human medicine favoring early surgical intervention, and the potential for significant functional impairment following humeral condylar fractures in dogs, this study aimed to explore the effect of surgical delay on radiographic and patient outcomes in canine humeral condylar fractures. The null hypotheses tested were that surgical delay would have no effect on fracture reduction, postoperative complications, or short-term patient outcomes. Secondarily, we aimed to explore reasons for and the nature of delays to surgery.

2 | METHODS

This study was reported in accordance with the STROBE-Vet guidelines[29] (Supplementary File S1). All data were obtained with written client consent granting permission for the anonymized use of patient information for research purposes.

2.1 | Data extraction and outcome definition

A retrospective review of medical records from a single small animal referral hospital in the UK was conducted. Records from January 2018 to June 2025 were searched for dogs diagnosed with humeral condylar fractures that subsequently underwent open reduction and internal fixation. Dogs were excluded if a minimum of 28-day postoperative orthopedic and radiographic follow-up was unavailable. Preoperative clinical data included patient age at the time of surgery, breed, bodyweight, sex and neuter status, primary surgeon and surgeon type, laterality, fracture etiology, and fracture characteristics. Fractures were considered non-traumatic if there was no history of trauma, if there was intracondylar sclerosis on imaging or intraoperatively, or if humeral intracondylar fissure was identified in the contralateral humerus.[11] Surgeon type was defined categorically as a board-certified specialist, non-board-certified clinician, or resident under direct supervision. Preoperative non-clinical data included the day of the week of the fracture event, the day of the week of referral presentation, and the day of the week of surgery. From these, three delay intervals were calculated in whole days, fracture to referral (defined as the pre-hospital delay), referral to surgery (defined as the hospital delay), and the total delay (defined as the combined pre-hospital and hospital delay). Operative clinical data included fixation technique, transcondylar screw angle,[18] and use of postoperative antibiotics. Postoperative outcome data included quality of fracture reduction, postoperative complications, short-term subjective outcome, and time to follow-up examination. Imperfect fracture reduction was defined as the presence of a visible intracondylar fracture gap or articular step defect on immediate postoperative radiographs and measured in millimeters.[19] Postoperative complications were defined categorically according to Cook and others.[30] Short-term subjective outcome was defined as excellent, good, fair, and poor according to Perry and others (Table 1).[11] Surgical site infections were diagnosed according to standard criteria.[31]

2.2 | Perioperative treatments

Surgical procedures were performed by board-certified surgeons (European College of Veterinary Surgeons or American College of Veterinary Surgeons), residents under direct supervision, or non-board-certified clinicians. Preoperative computed tomography (CT) was performed for diagnostic purposes and surgical planning. Perioperative cefuroxime or amoxicillin-clavulanate 20 mg/kg was administered 30 min preoperatively and repeated every 90 min intraoperatively. Postoperative antibiotic therapy was at the discretion of the attending surgeon. Following arthrotomy, fibrotic tissue was debrided from the fracture surface, where present, to facilitate anatomic reduction. All fractures were stabilized using a transcondylar screw in lag or positional fashion, combined with either epicondylar plate(s) and screws or epicondylar Kirschner wire(s). All transcondylar screws used were cortical bone screws (Orthomed; Huddersfield, UK), with condylar compression achieved with pointed reduction forceps. Anterograde or retrograde transcondylar screw hole drilling and joint debridement were performed at the discretion of the attending surgeon. A transcondylar screw washer was not used. For plate fixation, an appropriately sized string-of-pearls plate (Orthomed) or locking compression plate (Synthes; New Jersey) was used. Postoperative radiographs were obtained for assessment of alignment, apposition, and apparatus, reviewed by board-certified surgeons or a resident under direct supervision. The screw core diameter was divided by the condylar height to calculate the screw to condylar height (SCH) ratio.[32] Dogs were hospitalized for 24–48 h postoperatively for opioid analgesia and discharged with a non-steroidal anti-inflammatory drug for 2–8 weeks based on surgeon preference. Dogs were allowed 5 min of lead walks four to six times daily for 2 weeks following which the lead walks were gradually increased by 5 min per walk per week until veterinary follow-up. Follow-up orthopedic examination and radiographs were routinely requested 4–8 weeks postoperatively, based on surgeon preference, age of the dog, and the owner's availability. In the event of a complication, whether before or after routine follow-up, patients were re-examined and treated appropriately, as often as necessary until resolution of the complication.

TABLE 1 Clinical outcome scale as defined by Perry et al.[11]

Clinical outcome	Description of function
Excellent	No lameness, clinically within normal limits
Good	Mild lameness noted after extensive exercise
Fair	Mild to moderate intermittent lameness but consistent weightbearing
Poor	Non-weightbearing lameness

2.3 | Statistical analysis

Each operated humerus was treated as a single record. Dogs undergoing bilateral fracture repair contributed one record per humerus. Continuous clinical variables included age at surgery, bodyweight, and transcondylar screw angle. Categorical clinical variables included breed, sex, neuter status, surgeon, trauma type, fracture characteristics, fixation technique, use of a transcondylar screw in positional or lag fashion, and use of postoperative antibiotics. Days of the week were treated as categorical data, and delay intervals were analyzed continuously. Data normality was assessed with the Shapiro–Wilk test. Nonparametric data are expressed as median and interquartile range (IQR) and parametric data expressed as mean and SD. As the independent variable of interest, the range of delays was additionally reported. Quality of fracture reduction was modeled as a binary outcome using L1-regularized logistic regression with clinical variables as predictors. Postoperative complications were modeled using L1-regularized logistic regression including clinical variables and quality of fracture reduction as predictors. Short-term postoperative outcome was modeled using ordinal logistic regression (excellent = 4, good = 3, fair = 2, poor = 1) with clinical variables, quality of fracture reduction, and postoperative complications as predictors. To account for bilateral cases and data non-independence, cluster-robust standard errors were calculated with clustering at the level of the individual dog. The results of multivariable logistic regression were expressed as odds ratios and 95% CI. For sensitivity analyses, dogs with delays to surgery longer than seven days were excluded to assess the robustness of the results to extreme values. To quantify the relative importance of individual predictors, Shapley R^2 decomposition was performed by removing each predictor from the final models and calculating the change in the pseudo-R^2 value. To explore the relationship between fracture day of the week and surgical delay, differences in delay across days of the week were tested with the Kruskal–Wallis test, with post hoc pairwise comparisons performed using Dunn's test and the Holm adjustment for multiple testing. Statistical significance was defined as $p < .05$. All statistical analyses and data visualization were performed with pandas 2.2.2, numpy 2.0.2, scipy 1.16.1, scikit-learn 1.6.1, statsmodels 0.14.5, seaborn 0.13.2, and matplotlib 3.10.0 in Python version 3.12.11.[33–39]

3 | RESULTS

Retrospective record review yielded 217 consecutive humeral condylar fractures (210 dogs) treated by open reduction and internal fixation between January 2018 and June 2025. Six fractures (six dogs) were excluded due to failure to attend follow-up examination. Overall, 211 humeral condylar fractures (204 dogs) met the inclusion criteria. Three dogs underwent bilateral humeral condylar fracture repair for asynchronous fractures; two of these dogs had bilateral fractures of the lateral part of the humeral condyle and one of these dogs had a Y-T fracture and a fracture of the lateral part of the humeral condyle. Four dogs underwent bilateral synchronous humeral condylar fracture repair; two of these dogs had bilateral Y-T fractures and two of these dogs had bilateral fractures of the lateral part of the humeral condyle. The most common breeds were the French Bulldog ($n = 70$), English Springer Spaniel ($n = 49$), English Cocker Spaniel ($n = 31$) and Spaniel crosses ($n = 24$), with five or fewer of 19 other breeds. The median age at the time of surgery was 1.0 year (IQR: 4 months–5.0 years) and the median bodyweight was 13.7 kg (IQR: 7.5–18.5 kg). The median age of French Bulldogs and Spaniel breed dogs was 4 months (IQR: 3–5 months) and 4.2 years (IQR: 2.1–6.8 years) respectively. There were 121 male dogs (21 neutered) and 83 female dogs (15 neutered). There were 112 (53.1%) fractures of the left humerus and 99 (46.9%) fractures of the right humerus. Most fractures were sustained without trauma or during physiologic activity not expected to result in fracture ($n = 203$; 96.2%) with the remaining fractures ($n = 8$; 3.8%) having occurred after trauma. Of these, seven were sustained after a fall from height and the remaining one sustained in a road traffic accident. Fracture sclerosis was present in 142/211 (67.3%) humeral condylar fractures. Out of 193 fractures where imaging of the contralateral humerus was performed, partial and complete humeral intracondylar fissure were identified in 44/193 (22.8%) fractures and 43/193 (22.3%) fractures respectively. Imaging of the contralateral humerus was not performed in four fractures (4 dogs). Imaging of the contralateral humerus for humeral intracondylar fissure was irrelevant in the remaining 11 fractures (7 dogs) which either sustained bilateral synchronous or asynchronous fractures. Fractures of the lateral part of the humeral condyle ($n = 138$; 65.4%) were the most common fracture configuration followed by Y-T fractures ($n = 63$; 29.9%) and fractures of the medial part of the humeral condyle ($n = 10$; 4.7%). A total of 83 (39.3%) fractures were comminuted. The attending surgeon was a board-certified specialist in 152 fractures (72.0%), a non-board-certified clinician in 51 fractures (24.2%) and a resident under direct supervision in eight fractures (3.8%). Fracture fixation was via epicondylar plating in 160 fractures (75.8%) and epicondylar Kirschner wire(s) in 51 fractures (24.2%). Transcondylar screws were placed in lag fashion (107/217; 49.3%), positional fashion (34/217; 15.7%) and unrecorded (76/217; 35.0%). Dogs younger than seven months of age were significantly more likely to undergo fixation with epicondylar Kirschner wires ($p < .0001$). The median transcondylar screw angle was 9.7° (IQR: 3.7–15.3°). The mean SCH ratio was 0.297 ± 0.0417. An intracondylar fracture gap or articular step defect was visible on immediate postoperative radiographs in 28/211 fractures (13.3%), with a mean defect size of 1.16 ± 0.53 mm. Defects were less than 1.0 mm in 13/28 cases (46.4%), between 1.0 mm and 2.0 mm in 12/28 cases

(42.9%), and more than 2.0 mm in 3/28 cases (10.7%). Postoperative antibiotics were prescribed in 55/211 fractures (26.1%).

Fracture events were approximately evenly distributed across all days of the week. Referral presentations occurred mostly on weekdays, with a minority of cases presenting on weekends. Fracture repair was performed exclusively on weekdays (Figure 1). The median prehospital delay was 1 day (IQR: 1–2 days; range: 0–50 days). The median hospital delay was 1 day (IQR: 0–1 days; range: 0–4 days). The median total delay was 2 days (IQR: 1–3 days; range 0–50 days). The day of the fracture event was associated with the total delay to surgery, with fractures occurring on Friday or Saturday (Kruskal–Wallis $p < .001$ and Dunn's post hoc $p < .05$ in the relevant paired comparisons) resulting in a longer total delay compared with other days of the week (Table 2).

Postoperative follow-up data were obtained at a median of 43 days (IQR: 34–59.5 days). Postoperative complications occurred at a median of 28 days (IQR: 17–44 days). Complications were noted in 55/211 humeri (26.1%). Of these, 17 (8.1%) were minor complications, 25 (11.8%) were major surgical complications, 12 (5.7%) were major medical complications, and one (0.5%) was a catastrophic complication. All minor complications were seromas that did not require additional treatment. Major surgical complications included transcondylar screw loosening ($n = 2$), transcondylar screw breakage ($n = 2$), epicondylar plate and screw failure ($n = 10$), implant migration necessitating implant removal ($n = 9$), wound dehiscence ($n = 1$), and implant-associated surgical site infection necessitating implant removal ($n = 1$). Major medical complications were superficial incisional surgical site infection ($n = 8$), and septic arthritis ($n = 4$). The one catastrophic complication was a Y-T fracture with repeated implant failure and non-union requiring forequarter amputation. Short-term outcomes were rated as excellent in 120 cases (56.9%), good in 78 cases (37.0%), fair in 11 cases (5.2%), and poor in two cases (0.9%).

In the multivariable model evaluating quality of fracture reduction, an increase in total delay to surgery was associated with an increased risk of an intracondylar gap or articular step defect (OR = 3.86 per additional day, 95% CI: 2.04–7.29, $p < .001$). Comminuted fractures were more likely to result in an intracondylar gap or articular

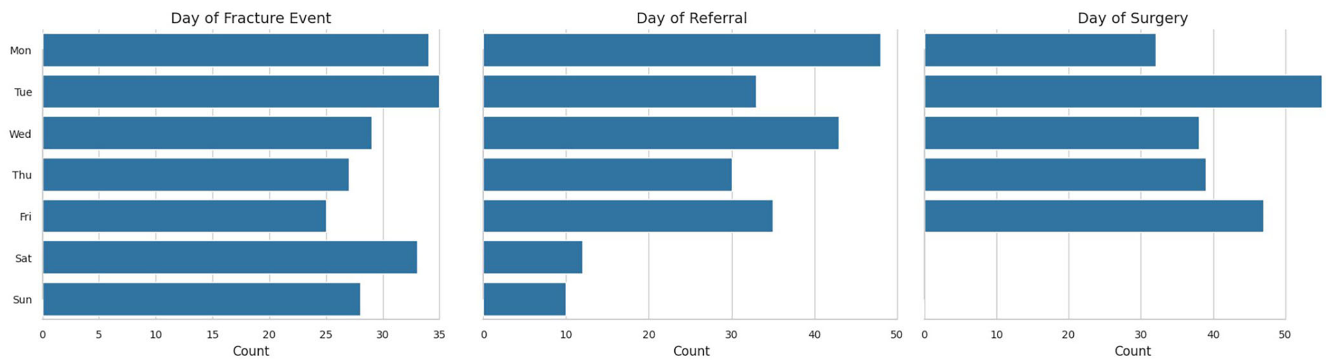

FIGURE 1 Distribution of the fracture event, referral presentation, and surgery by day of the week.

TABLE 2 Total delay by day of the week of the fracture event, with Dunn's post hoc *p*-values showing pairwise comparisons where median total delays differ.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Total delay	2 (1–3)	2 (1–2)	2 (1–2)	1 (1–4)	**4 (3–4)**	**3 (2–3)**	2 (2–3)
Monday		1.000	1.000	1.000	**.003**	**.045**	1.000
Tuesday			1.000	1.000	**< .001**	**.002**	1.000
Wednesday				1.000	**< .001**	**.004**	1.000
Thursday					**< .001**	**.011**	1.000
Friday						1.000	**.02**
Saturday							.2624
Sunday							

Note: The gray shaded cells are empty and have no values. Significance is defined as $p < .05$ (in bold).

step defect (OR = 40.19, 95% CI: 4.64–105.57, $p = .002$). Breed, fracture configuration, transcondylar screw angle, primary surgeon, surgeon type, fixation technique, and transcondylar screw fashion were included in the multivariable model but were not independently associated with risk of an intracondylar gap or articular step defect.

In the multivariable model evaluating postoperative complications, presence of an intracondylar gap or articular step defect resulted in higher odds of postoperative complications (OR = 5.92, 95% CI: 1.44–24.36, $p = .01$). Y-T fractures were associated with an increased risk of postoperative complications (OR = 3.56, 95% CI: 1.11–11.38, $p = .03$) relative to unicondylar fractures. Breed, fracture comminution, transcondylar screw angle, primary surgeon, surgeon type, fixation technique, transcondylar screw fashion, use of postoperative antibiotics, and the SCH ratio were included in the multivariable model but were not independently associated with postoperative complications.

In the multivariable model evaluating short-term outcome, presence of an intracondylar gap or articular step defect was associated with an increased risk of a poorer short-term outcome (OR = 0.13, 95% CI: 0.04–0.42, $p = .001$). The presence of postoperative complications increased the risk of a poorer short-term outcome (OR = 0.38, 95% CI: 0.17–0.87, $p = .02$). Unicondylar fractures were more likely to have a better short-term outcome relative to Y-T fractures (OR = 8.48, 95% CI: 2.58–27.88, $p < .001$). Older age at surgery was associated with lower odds of a better short-term outcome (OR = 0.98 per additional year, 95% CI: 0.96–0.99, $p < .001$). Breed, transcondylar screw angle, primary surgeon, surgeon type, fixation technique, transcondylar screw fashion, and use of postoperative antibiotics were included in the multivariable model but were not independently associated with short-term outcome.

There were 14 outliers (14 fractures in 14 dogs) with delays to surgery of more than 7 days (8 days, $n = 2$; 9 days, $n = 2$; 10 days, $n = 3$; 11 days, $n = 2$; 12 days, $n = 1$; 13 days, $n = 1$; 20 days, $n = 1$; 23 days, $n = 1$; 50 days, $n = 1$). Sensitivity analysis excluding these outlying cases yielded regression results consistent with the unrestricted analysis, demonstrating robustness of results to outliers. Pseudo-R^2 decomposition showed that delay to surgery contributed the most to model variance, with an absolute pseudo-R^2 of 0.4597, with other covariates contributing minimally (Figure 2). The full multivariable model had a pseudo-R^2 value of 0.5331.

4 | DISCUSSION

This study examined the effect of surgical delay on quality of fracture reduction, postoperative complications, and short-term outcome following humeral condylar fracture repair. We found that longer delays were associated with a higher risk of an intracondylar fracture gap or articular step defect. In turn, these reduction defects were linked to increased complication risk and poorer short-term outcomes. Although delay was not directly associated with complications or outcome, the sequential associations identified suggest that surgical delay may indirectly affect patient outcomes through associations

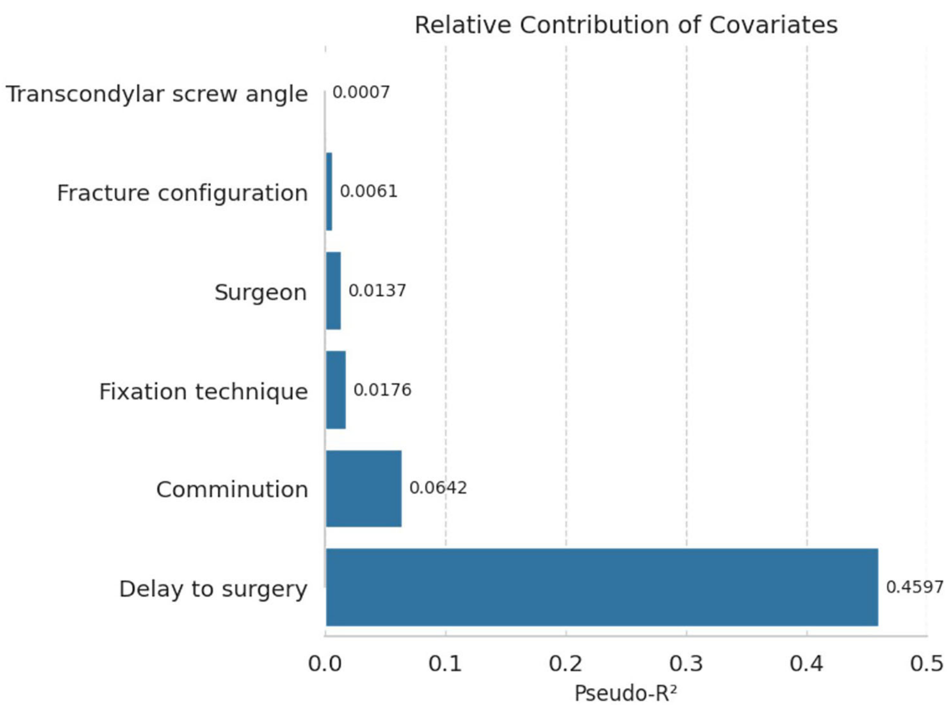

FIGURE 2 Pseudo-R^2 decomposition of the multivariable model representing the absolute contribution of each predictor to model variance.

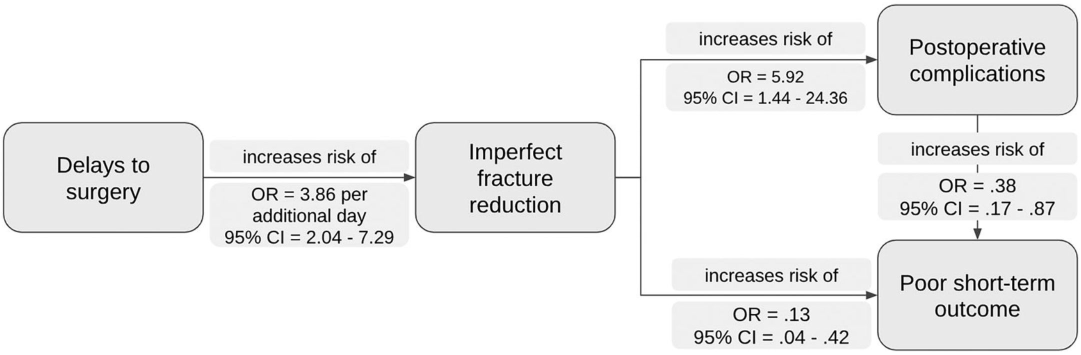

FIGURE 3 Mediation diagram showing sequential associations between the independent variable and postoperative outcomes, and among postoperative outcomes.

with fracture reduction quality (Figure 3). Therefore, the null hypotheses were rejected.

Delays to surgical stabilization of an articular fracture may compromise the quality of fracture reduction by allowing soft tissue contracture and fibrous callus formation, which hinder attempts at anatomic reduction. Experimental studies have shown that delayed fracture stabilization results in greater callus formation at the fracture site,[40] and that disruption of the fracture hematoma impairs fracture healing.[41] While direct clinical veterinary evidence is lacking, humeral condylar fractures presenting in a delayed fashion are anecdotally more challenging to reduce because of the increased organizing hematoma or fibrous callus within the fracture site. This is the first study to examine the clinical effect of surgical delay on achieving anatomic reduction of the humeral condyle, demonstrating that longer delays are associated with a higher risk of sub-optimal reduction. Although increasing delay to surgery was associated with reduced quality of fracture reduction, the relatively short median delay observed in this cohort suggests that classical mechanisms such as fibrous callus formation or soft tissue contracture are unlikely to fully explain this finding. Alternative explanations may include progressive fracture instability, ongoing micromotion at the fracture site, soft tissue swelling, or system-level factors influencing surgical timing and conditions. As such, the relationship observed in this study should be interpreted as an association rather than evidence of a specific biological mechanism. Similarly, comminuted articular fractures are inherently more difficult to reduce and stabilize,[42] and we show that fracture comminution in the canine humeral condyle is a risk factor for sub-optimal reduction. Although transcondylar screws diverging from the epicondylar line have previously been reported to increase the risk of an intracondylar fracture gap,[18] controlling for potential confounders in our multivariable model showed no association between the quality of reduction and the transcondylar screw angle or the operating surgeon.

This study showed that an intracondylar fracture gap or articular step defect increased the risk of postoperative complications. This is in agreement with previous research where intracondylar fracture gaps and articular step defects increased the risk of implant failure and negatively affected fracture healing.[18,19] Mechanically, a fracture gap significantly reduces construct stiffness and stability, and biomechanical studies have demonstrated that even millimeter gaps can reduce mechanical stability and increase fixation stress, especially when there is a lack of bone contact.[43] Biologically, poor fracture apposition leads to excessive interfragmentary motion, which promotes the formation of fibrous tissue instead of bone, with experimental models showing that larger gaps in an unstable mechanical environment lead to fibrous nonunion and poor bone healing.[44] Fracture comminution was not independently associated with postoperative complications on multivariable analysis, in agreement with a previous study.[11] However, the effect of comminution on complication risk may be indirectly mediated via its association with suboptimal fracture reduction. Notably, we did not find fixation technique to be a risk factor for postoperative complications, although a selection bias was demonstrated in that skeletally immature dogs were more likely to undergo epicondylar Kirschner wire fixation. The literature on epicondylar fixation technique is mixed, with certain studies reporting fewer complications with epicondylar plating[4,11,21] while other studies find no difference between epicondylar plates and Kirschner wires.[20,22] In our study, epicondylar fixation technique was not independently associated with complications in multivariable analysis. Taken together, these findings suggest that achieving anatomic reduction and stable fixation may be more important determinants of outcome than implant selection alone. However, this study was not designed to compare fixation methods, and no conclusions regarding the relative suitability of specific implant types can be drawn.

We showed that suboptimal fracture reduction and the presence of postoperative complications increased the risk of a poorer short-term outcome. As discussed earlier, sub-optimal reduction compromises the biomechanical environment and predisposes to postoperative complications, and similar mechanisms may predispose to a poor short-term outcome. Articular fractures require anatomic reduction and rigid fixation to restore joint function, and failure to achieve this may result in accelerated cartilage degeneration, joint incongruity, and persistent lameness.[45] Similarly, postoperative complications such as surgical site infection or implant failure directly cause pain and morbidity. Our findings unsurprisingly show that postoperative complications worsen functional short-term outcomes. This finding has been previously reported in canine humeral condylar fracture repair[11] and corrective surgery for medial patellar luxation.[46] We found that Y-T fractures were independently associated with both an increased risk of postoperative complications and a poorer short-term outcome. Previous studies are restricted to either a single humeral condylar fracture configuration[11,18,19,47] or studies examining a limited range of breeds[4,21] and no studies have compared intracondylar to unicondylar fractures. Y-T fractures are known to be technically demanding, requiring additional tissue dissection and longer anesthetic and surgical time. This study represents the largest series of canine humeral condylar fractures to date and we show that Y-T fractures are associated with worse short-term postoperative outcomes. Overall, our findings show that anatomic reduction of the humeral condyle is critically important in mediating postoperative complication rates and short-term outcome.

Pseudo-R^2 decomposition of covariate contributions showed that the most important covariate in the model was the delay to surgery. However, this metric reflects the relative statistical contribution of variables to model fit and should not be interpreted as evidence of causal dominance, which cannot be inferred from this observational study design. Covariate decomposition quantifies the relative contribution of each covariate towards model variance. This is the first study in veterinary orthopedics to investigate system factors and how they relate to postoperative outcomes, specifically examining the total delay to surgery in canine humeral condylar fractures. Our findings suggest that while various statistically significant clinical covariates were found, these were relatively less important in mediating the outcomes measured. Fracture configuration and comminution were significant covariates but these are immutable patient factors, and both were found to be relatively less important than the total delay to surgery. Similarly, surgeon factors including fixation technique were found not to be significant in explaining postoperative outcomes or in decomposition analysis.

Delays to surgery have been associated with poorer patient outcomes in articular and juxta-articular fractures in humans,[24–26] but the reasons for this association are still debated. The relevant human studies typically investigate geriatric patients with hip or other juxta-articular fractures, where systemic comorbidities such as cardiovascular disease, diabetes, or frailty act as important confounders influencing both timing of surgical intervention and postoperative outcomes.[48] In contrast, dogs sustaining humeral condylar fractures with minimal trauma likely have underlying humeral intracondylar fissure.[6,11,49] These dogs are generally young to middle-aged and otherwise healthy with no traumatic comorbidities. As such, the observed effect of surgical delay in this population is less likely to be attributable to patient comorbidity needing preoperative stabilization, and may instead reflect the direct consequences of delayed surgical intervention. This interpretation is supported by our pseudo-R^2 decomposition, which identified surgical delay as the most influential covariate in explaining outcome variance, supporting the possibility that surgical delay itself may contribute to outcome variation rather than merely serving as a proxy for unmeasured confounders.

We describe system-level factors contributing to poor patient outcomes, an area that remains underinvestigated in veterinary surgery. While previous studies of canine humeral condylar fractures have focused on patient-level variables and surgical decision-making, our exploratory and novel findings suggest that delays to surgery may be of equal or greater importance. System-level factors have similarly been implicated in other acute conditions such as canine thoracolumbar intervertebral disc extrusion.[50] In our sample, most dogs underwent timely surgical stabilization within 2 days. When prolonged delays occurred, these were usually attributable to a prehospital delay, reflecting the variability in owner decision-making, referral processes, and access to care. In contrast, the hospital delay was relatively short and more predictable. We also showed that fracture events occurring on Friday or Saturday systematically experienced longer delays, which may be reflective of the access to primary care, and subsequently, referral care. Although this study examines the operations of a single referral center only, avoiding elective fracture repair on weekends is anecdotally common among small animal orthopedic surgeons. In conjunction with our findings that a delay to surgery explained the majority of variance compared to other covariates, quality improvement should therefore be directed at modifiable system factors instead of patient factors, which are inherently non-modifiable. Our findings suggest that by prioritizing system-level optimization in the form of case triage, theater and staff availability, and timely surgical intervention, there is potential to improve patient-centered postoperative outcomes. However, these findings are novel and should be seen as hypothesis-generating, before widespread changes to fracture management can be recommended.

This study represents the largest series of canine humeral condylar fractures to date, and our follow-up methodology minimized attrition bias, with follow-up-data unavailable in only 2.8% of dogs. The dataset is otherwise representative of dogs presenting with humeral condylar fracture with young to middle-aged French Bulldogs and Spaniel breed dogs over-represented.[11,19] The frequency of comminuted humeral condylar fractures in this study was similar to that previously reported.[11] The postoperative complication rate was also within the range of that previously reported.[11,17–20] Nevertheless, several limitations are acknowledged. The retrospective, single-institutional design may limit the generalizability of our findings to other referral hospitals, which may have used intraoperative fluoroscopic guidance. Our findings may also not apply to dogs being managed in non-referral settings. Anesthetic and surgical time have been reported to be risk factors for poorer outcomes[18] but were not consistently available from retrospective record review and could not be evaluated. Debridement of the fracture surface was not standardized and would have been a source of uncontrolled heterogeneity in treatment. Assessment of immediate postoperative radiographs for quality of fracture reduction is inherently subjective, with considerable variability in the criteria and measures reported across the literature. The rate of imperfect fracture reduction found in our study aligned more closely with those of Moffatt and others at 27.7%[47] than with other studies, where rates of 41.5%–69.0% were reported.[11,18] The presence of a persistent intracondylar fissure was also not assessed as postoperative radiographic assessment is likely to underestimate the true rate of persistent fissures.[51] The use of non-steroidal anti-inflammatory drugs beyond 2 weeks postoperatively may have also had a negative effect on fracture healing.[52] Postoperative CT would better assess postoperative fissure healing but this was not available retrospectively and even then, the metal artifact from the transcondylar screw limits proper assessment of intracondylar fracture healing. Radiographic assessment of humeral condylar fracture reduction may not be as reliable as CT and future studies should consider the use of immediate postoperative CT for precise outcome definition.[53] Our study only assessed short-term subjective outcomes and how our findings impact long-term outcomes are not known. The short-term outcome studied may not correlate with long-term outcome, with a previous study reporting that accuracy of fracture reduction did not correlate with long-term outcomes.[9] The pseudo-R^2 value of the full model in decomposition analysis was approximately 0.53, indicating that nearly half of model variance remains unexplained and may reflect unmeasured confounding or other uninvestigated factors, system or otherwise.

In summary, this study suggests that surgical delay is an important system-level factor associated with the quality of fracture reduction, postoperative complications, and short-term outcomes in canine humeral condylar fracture repair. Anatomic reduction of the humeral condyle appeared to mediate the effect of surgical delay towards postoperative complications and short-term outcomes. We show that while patient factors such as fracture configuration and comminution were also associated with reduction quality, modifiable system factors governing access to surgery are comparatively more important towards outcome variance. System-level optimization may represent a new opportunity to improve patient-centered outcomes in this patient population.

AUTHOR CONTRIBUTIONS

Low, D, BVetMed, CertAVP(GSAS), PGCertVPS, MRCVS: Study conception, study design, data collection, data analysis, interpretation of results, and manuscript writing. Manou M, DVM, DipECVS, MRCVS: Data analysis, interpretation of results, and manuscript writing. Rutherford S, BVMS, CertSAS, DipECVS, FRCVS: Data analysis, interpretation of results, and manuscript writing. All authors approved the final manuscript.

CONFLICT OF INTEREST STATEMENT

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

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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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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