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# Impact of breed on canine humeral condylar fracture configuration, surgical management, and outcome

**Carlos Sanchez Villamil CertAVP, DVM**[1] | **Andrew S. J. Phillips BVetMed, MVetMed, DECVS**[1] | **Camilla L. Pegram BVetMed MRes**[2] | **Dan G. O'Neill MVB, BSc (Hons), MSc (VetEpi), PhD**[2] | **Richard L. Meeson MA, VetMB, PhD, MVetMed, DECVS**[1]

[1]Department of Clinical Science and Services, Royal Veterinary College, University of London, North Mymms, Hertfordshire, United Kingdom

[2]Department of Pathobiology and Population Sciences, Royal Veterinary College, University of London, North Mymms, Hertfordshire, United Kingdom

**Correspondence**
Dr Richard Meeson, Department of Clinical Science and Services, Royal Veterinary College, University of London, North Mymms, Hertfordshire, AL9 7TA, United Kingdom.
Email: rmeeson@rvc.ac.uk

**Abstract**

**Objective:** To report the prevalence, configuration, risk factors, fixation methods and outcomes after repair of humeral condylar fractures (HCF) in dogs.

**Study design:** Retrospective nested cohort study.

**Sample population:** One hundred twelve dogs.

**Methods:** Medical records of dogs referred between January 2010 and August 2018 were searched for HCF. Demographics, fracture configuration, repair, and complications were obtained from medical records. Radiographs were assessed for fracture reduction, implant positioning, and bone healing. Short-term radiographic and clinical outcomes, and long-term owner-assessed outcome was determined. Associations between these variables were statistically analyzed.

**Results:** Dogs with HCF represented 112 of 43 325 (0.26%, 95% CI 0.22-0.31) referrals. French bulldogs and spaniel breeds were predisposed to HCF ($P < .02$). French bulldogs were 6.58 times (95% CI 1.62-26.7) more likely than other breeds to have a medial HCF ($P = .008$). Epicondylar plate fixation was associated with reduced complications compared with lag screws and Kirschner wires ($P = .009$). Lameness was scored as 1 of 5 (median) in the 85 dogs with initial follow-up (median 6 weeks) after HCF repair. Outcome was considered excellent in 26 of 31 dogs with long-term follow-up (median 36 months).

**Conclusion:** French bulldogs and spaniels were predisposed to HCF, and medial HCF were more common in French bulldogs. Epicondylar plate fixation was associated with reduced complications.

**Clinical significance:** French bulldogs are predisposed to HCF, including medial HCF. Epicondylar plate fixation is recommended over other epicondylar fixation methods to reduce complications.

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# 1 | INTRODUCTION

Humeral condylar fractures (HCF) account for nearly 50% of all humeral fractures in dogs[1] and are classified into lateral, medial, or intercondylar/bicondylar configurations.[2] Lateral HCF predominate, with prior articles reporting the distribution of lateral, medial, and bicondylar fractures as 62.1%, 7.7% and 30.2% respectively.[1,3-7] Humeral condylar fractures are most commonly diagnosed in skeletally immature dogs under 1 year of age[8] or in adult dogs with underlying humeral intracondylar fissures (HIF).[9] Some breeds have been associated with HCF, namely spaniel breeds (English springer spaniel, cocker spaniel and Cavalier King Charles spaniel),[4,8] French and English bulldogs,[6] Yorkshire terriers,[5,6] and pinschers.[6]

Methods of repair include wire,[10] rush pins,[11] transcondylar screws,[12] Kirschner wires (K-wires),[13] self-compressing Orthofix pins,[14] cannulated screws,[15] and closed reduction with subsequent internal fixation.[16] A transcondylar screw in lag fashion with a supracondylar point of fixation to prevent rotation has been most commonly performed.[17-19] Complication rates after HCF repair vary between 15% and 33%[5,8,14,16,20,21] and include nonunion, fixation failure, infection, seroma formation, reduced range of motion (ROM), elbow arthritis, and ongoing lameness. Several factors have been proposed to affect the complication rate including method of fixation,[19] presence of HIF,[16,18] surgical time, presence of postoperative intracondylar fracture gap, and transcondylar screw angle.[21] In a small series of 16 hunting and working farm dogs, the prognosis for return to work after stabilization of HCF was reported as good.[7] Nevertheless, 28% to 57% of dogs have been reported to experience long-term pain or lameness after surgery.[1,4,8]

Breed populations have changed remarkably over the last 25 years.[22] During this period, the authors have noticed a change in presentation of HCF, with many more medial HCF noted in the French bulldog. Most clinical studies in which HCF has been investigated were conducted pre-1995.[1,4-6,8] Since then, to the best of the authors' knowledge, no epidemiological studies have been conducted to accurately determine the risk of HCF, nor have the predisposing factors, fracture morphology, or repair method been assessed for impact on complications and outcome.

The objectives of this study were (1) to report the prevalence, fracture configuration and risk factors for HCFs within a contemporary referral population of dogs; and (2) to describe methods of repair and outcome, and to identify risk factors for complications. The hypotheses were that (1) French bulldogs have an increased odds of HCF compared with non-spaniel breeds, (2) French bulldogs are predisposed to medial HCF compared with other breeds, (3) HCF epicondylar repair with plates has a lower complication risk than other methods of repair, and (4) breed and fracture morphology are not associated with a difference in clinical outcome.

# 2 | MATERIALS AND METHODS

## 2.1 | Study population

The clinical database of the Royal Veterinary College, Queen Mother Hospital for Animals (University of London), was searched to identify all dogs with at least one electronic record for referral veterinary care from January 1, 2010 through August 31, 2018. The medical records of all these dogs were reviewed to identify those that underwent HCF repair during the same study period. Breed, age (years), sex, neuter status, and body weight (kilograms) were recorded for all dogs.

## 2.2 | Radiographic data collection

Only dogs with preoperative and postoperative orthogonal radiographic projections were included in the study. Classifications for fracture morphology were lateral HCF, medial HCF, and bicondylar HCF, based on preoperative imaging. Fracture configuration was assessed from radiographs or computed tomography. Fracture repair in all dogs included a transcondylar screw with additional epicondylar fixation. Type of transcondylar screw, size, direction in the mediolateral plane, lag or positional placement, and whether a washer was placed were recorded. The epicondylar method of fixation was classified as K-wire(s) only, epicondylar screw(s) ± epicondylar K-wire(s), and plates ± epicondylar screw(s)/K-wire(s). Type and size of epicondylar implants and whether the plate system was locking or nonlocking were recorded. Immediate postoperative radiographs were reviewed for accuracy of fracture reduction and implant positioning. Fractures were categorized as reconstructed when the fracture gap was <0.5 mm at both the intracondylar and epicondylar regions of the fracture and nonreconstructed when the fracture gap was ≥0.5 mm on the basis of evidence that with digital radiographs, only a 0.25- to 0.5-mm difference between points can be differentiated.[23] Articular step defects (ASD) were measured and categorized as <1.5 mm and ≥ 1.5 mm because a 1.5-mm step induces detrimental supraphysiologic changes to cartilage loading.[24] Bone healing was assessed from follow-up radiographs and radiology reports and classified as complete or incomplete. The occurrence and nature of postoperative complications, time to complication, and complication treatment were recorded.

### 2.3 | Clinical data collection

Surgical reports and clinical notes were reviewed for reported intraoperative complications. Follow-up visits and time to follow-up (weeks) were recorded, and lameness score and ROM of the elbow were determined. Dogs with bilateral HCF were excluded for follow-up descriptive data because of the possible influence of the contralateral fracture on lameness assessment. Lameness scoring was based on a recognized numeric rating scale[25] with five levels of lameness severity: 0, clinically sound; 1, minimally detectable lameness; 2, mild lameness; 3, moderate lameness; 4, severe lameness (carries limb when trotting but weight bearing when standing); and 5, could not be more lame (non–weight bearing when standing or trotting). Range of motion was classified as normal or reduced.

Complications were categorized according to a previously defined consortium classification.[26] Complications were also classified as postoperative implant-related complications (complications affecting the position and/or integrity of the implants, without documentation of infection), infection-related complications (suspected infection or confirmed infection based on clinical signs, cytology, and bacterial culture results), intraoperative (any complication occurring during fracture repair and detected at the time or on immediate postoperative radiographs), and other (any other complication not falling into previous categories). Long-term follow-up was owner-assessed with the canine brief pain inventory[27] (CBPI) and an additional questionnaire (see Supporting Information).

### 2.4 | Statistical analysis

#### 2.4.1 | Epidemiology of HCF

Sample size calculations performed in Epi Info (Centers for Disease Control and Prevention) estimated that at least 13 261 dogs must be studied from a total population of 43 325 dogs to estimate the prevalence of a disease with an expected frequency of 0.5% within 0.1% precision and 95% confidence level. In the current study, all 43 325 dogs were studied. Variables were categorized according to similar criteria in both analyses. Age was categorized as <1 and ≥ 1 year, with the age of HCF dogs calculated at the time of fracture treatment and the age of non-HCF dogs calculated at the date of the final record during the study period. Dogs were categorized as a breed-variable by using standardized breed terms.[28] To maintain sufficient power for analysis, the breed variable included specific breeds with at least six HCF. Remaining dogs were grouped as purebred-other and crossbred in the HCF vs non-HCF analysis and other in the analysis of HCF only. A combined spaniels category that included cocker spaniels and English springer spaniels was created for comparison to French bulldogs. Cavalier King Charles spaniels were excluded from the spaniels group because of their chondrodystrophic morphology, which is similar to that of French bulldogs. Sex was examined as male and female. Neuter status was examined as neutered and intact, with the status recorded at the same time point as for age variable. Data were exported to SPSS version 24.0 (IBM, Armonk, New York) for statistical analysis. Descriptive statistics were reported separately for HCF and non-HCF. Continuous variables were summarized by using median, interquartile range (IQR), and range (if not normally distributed). Mann–Whitney *U* test, $\chi^2$ test, and Fisher's exact test were used as appropriate for comparison of demographic data between HCF and non-HCF and for comparison of demographic data between each fracture morphology.[29] In the analysis of HCF vs non-HCF, binary logistic regression modeling was used to evaluate univariable association between the risk factor of primary interest (breed) and fracture diagnosis. In the analysis of HCF only, two separate models were built to evaluate lateral vs medial HCF and bicondylar vs unicondylar HCF (lateral and medial combined). Dogs with bilateral HCF were excluded from the statistical analysis because it is not possible to completely attest for the independence of one fracture from the other. In all models, additional variables of age, sex, and neuter status were also assessed as potential confounders. Explanatory variables with liberal univariable association with HCF ($P < .2$) were carried forward for multivariable logistic regression modeling. Model building used a backward stepwise approach. Potential confounding factors were assessed by checking for a marked (>10%) change in the odds ratio after removal of the variable from the model. Collinearity was investigated by examining the variance inflation factor (VIF) and tolerance, with collinearity indicated if VIF >10 and tolerance <0.1. Model fit was assessed with the Hosmer-Lemeshow test and by calculating the area under the receiver operation characteristic curve. Statistical significance was set at the 5% level.

#### 2.4.2 | Fracture morphology and repair method on complication development

Dogs with bilateral HCF were excluded from statistical analysis as previously described. The $\chi^2$ test and Fisher's exact test were used as appropriate for comparison of data between categorical variables: (1) fracture morphology and complication type (minor, major, catastrophic), (2) method of epicondylar fixation and implant-related complications (implant related vs non–implant related), and (3) fracture reconstruction and implant-related complications (as before). For analyses 2 and 3, dogs with both implant-related and non–implant-related complications were excluded because the complications may not have been independent of each other. Binary logistic regression modeling was used to evaluate univariable association between breed and age as well as complications (yes or no). Breed and age variables were classified as previously described for the study group.

## 3 | RESULTS

### 3.1 | Demographics

One hundred twelve dogs with HCF were identified in a population of 43 325 referral dogs, providing an overall HCF prevalence of 0.26% (95% CI 0.22-0.31). Three dogs had bilateral fractures, providing a total of 115 HCF. The most common breed types among HCF dogs were French bulldog (24.1%, n = 27), English springer spaniel (28.8%, n = 21), cocker spaniel (11.6%, n = 13), crossbreed (10.7%, n = 12), and Cavalier King Charles spaniel (5.4%, n = 6), which differed from the most common breed types among non-HCF dogs, which were crossbreeds (15.1%, n = 6507), Labrador retriever (9.3%, n = 3999), cocker spaniel (4.6%, n = 1983), Staffordshire bull terrier (3.8%, n = 1652), and Jack Russell terriers (3.5%, n = 1511; $P < .001$). The breeds with the highest HCF prevalence were French bulldog 2.40% (95% CI 1.62-3.52), English springer spaniel 2.25% (95% CI 1.43-3.48), cocker spaniel 0.62% (95% CI 0.34-1.09), Cavalier King Charles spaniel 0.47% (95% CI 0.19-1.08), and crossbreeds 0.18% (95% CI 0.10-0.33).

The median age of HCF dogs was 0.4 years (IQR, 0.29-3.95; range, 0.15-11.21), which was younger than the median age of non-HCF dogs of 6.3 years (IQR, 2.94-9.62; range, 0.003-20; $P < .001$). The median weight of HCF dogs was 9.5 kg. There was no difference identified between the sex of HCF dogs (58.9%, n = 66 male; 41.1%, n = 46 female) and non-HCF dogs (55.9%, n = 24 122 male; 44.1%, n = 19 045 female; $P = .567$). Fewer HCF dogs were neutered (77.7%, 87 intact; 22.3%, 25 neutered) compared with non-HCF dogs (34.6%, 14 940 intact; 65.4%, 28 273 neutered; $P < .001$).

English springer spaniels ($P < .001$), French bulldogs ($P < .001$), cocker spaniels ($P = .003$), and Cavalier King Charles spaniels ($P = .02$) were predisposed to HCF on multivariable analysis. Being intact and being <1 year old were also predisposing factors according to multivariable analysis ($P < .001$; Table 1).

### 3.2 | Fracture configuration

The overall proportions of lateral HCF, bicondylar HCF, and medial HCF were 75 of 115 (65.2%), 30 of 115 (26.1%), and 10 of 115 (8.7%), respectively; proportions were 13 of 27 (48.1%), eight of 27 (29.6%), six of 27 (22.2%), respectively, in the French Bulldog; and 21 of 26 (80.8%), five of 26 (19.2%), and zero of 26 (0%), respectively, in the springer spaniel (Table 2). French bulldogs were 6.58 times more likely than other dogs to have a medial HCF (95% CI 1.62-26.70, $P = .008$).

There was no difference between the median age of lateral HCF dogs (4.5 months; IQR, 3-5.6; range, 1.9-135.8), medial HCF dogs (3.8 months; IQR, 3-5.6; range, 2.8-43.7), or bicondylar HCF dogs (6.5 months; IQR, 3.8-42.3; range, 2.8-96.7; $P = .222$). There was no difference between the sex of lateral HCF (58.6%, 41 male; 41.4%, 29 female), medial HCF (50%, five male; 50%, five female), or bicondylar HCF (69%, 20 male; 31%, nine female; $P = .487$) dogs. There was no difference between the neuter status of lateral (78.6%, 55 intact; 21.4%, 15 neutered), medial (90%, nine intact; 10%; one neutered) or bicondylar HCF (75.9%, 22 intact; 24.1%, seven neutered; $P = .636$) dogs.

### 3.3 | Fracture repair

Bilateral HCF (three dogs, six fractures) and HCF with both implant-related and non–implant-related complications (n = 3) were excluded to maintain consistency between the statistical analysis and the descriptive data. One of the HCF with implant-related and non–implant-related complications was in a dog that had bilateral HCF, so the total number of HCF excluded for analysis was eight (107/115 included).

Information about the size of the transcondylar screw was available for 101 of 107 (94.4%) HCF. Among these, screw diameters included 4.5 (n = 35), 3.5 (n = 17), 2.7 (n = 24), 2.4 (n = 10), and 2 mm (n = 15). Information about the type and direction of the transcondylar screw was available for 105 of 107 (98.1%) HCF. A cortical screw was used for 93/105 (88.6%) of the transcondylar screws placed, with a small number of shaft screws 8/105 (7.6%) and headless self-compressing cannulated screws 4/105 (3.8[MR1] %). Ninety-one screws were placed in lateromedial direction, while 14 screws were placed in mediolateral direction. Information about interfragmentary compression was available for 91 of 107 (85%) HCF, with 80 lag and 11 positionally placed screws. Fifty screws were placed with an adjunct washer.

**TABLE 1** Risk factors for humeral condylar fractures

| Variable | Category | OR | 95% CI | Category *P*-value | Variable *P*-value |
|---|---|---|---|---|---|
| Breed | Crossbreed | Base | | | <.001 |
| | English springer spaniel | 15.52 | 7.50-32.13 | <.001 | |
| | French bulldog | 8.12 | 4.06-16.22 | <.001 | |
| | Cocker Spaniel | 3.34 | 1.51-7.38 | .003 | |
| | Cavalier King Charles spaniel | 3.25 | 1.21-8.75 | .020 | |
| | Other purebred | 0.55 | 0.28-1.07 | .077 | |
| Age, y | ≥1 | Base | | | |
| | <1 | 8.50 | 5.53-13.08 | <.001 | <.001 |
| Neuter status | Neutered | Base | | | |
| | Intact | 2.81 | 1.70-4.64 | <.001 | <.001 |

*Note*: In a population of dogs at a single institution (N = 43 325) identified with a final multivariable model.
Abbreviation: OR, odds ratio.

**TABLE 2** Distribution of fracture configuration within breeds

| Breed | Lateral HCF | Bicondylar HCF | Medial HCF | Total HCF |
|---|---|---|---|---|
| French bulldog | 13 | 8 | 6 | 27 |
| English springer spaniel | 21 | 5 | 0 | 26 |
| Cocker spaniel | 7 | 6 | 0 | 13 |
| Crossbreed | 7 | 2 | 1 | 10 |
| Cavalier King Charles spaniel | 3 | 1 | 2 | 6 |

Abbreviation: HCF, humeral condylar fracture.

Epicondylar fixation included at least one plate, ± epicondylar screw(s) ± epicondylar K-wire(s), in 64 HCF. For 37 HCF, a plate was placed on the lateral aspect of the humerus, of which 35 were unicondylar fractures, and two were bicondylar fractures. For seven HCF, a plate was placed on the medial aspect of the humerus, of which three were unicondylar fractures, and four were bicondylar fractures. Twenty bicondylar HCF were bilaterally plated. Locking plates were used in 53 HCF, and nonlocking plates were used in 11 HCF. Among the 43 HCF without a plate, 15 HCF received epicondylar screw(s) ± epicondylar K-wire(s), and 28 HCF received epicondylar K-wire(s) only.

Information about fracture reconstruction and ASD was available for 100 of 107 (93.5%) and 97 of 107 (90.7%) HCF, respectively. Fracture reconstruction was achieved in 36 of 100 (36%) HCF, and the ASD was <1.5 mm in 92 of 97 (94.8%) HCF.

## 3.4 | Short-term outcome

Twenty-five of 112 (22.3%) dogs were lost to follow-up. One dog lost to follow-up had bilateral fractures, and the other two bilateral HCF dogs were excluded. A total of 85 dogs (85 HCF) presented at first follow-up (range, 1-12 weeks; median, 6). Information about lameness, elbow ROM, and bone healing at first follow-up was available for 73 of 85 (85.9%), 55 of 85 (64.7%), and 74 of 85 (87.1%) HCF dogs, respectively. At first follow-up, the median lameness score was 1 (minimally detectable lameness); 38 of 55 (69.1%) dogs had reduced elbow ROM, and bone healing was complete in 13 of 74 (17.6%) dogs. Twenty-five of the 85 (29.4%) dogs presenting for first follow-up had more than one follow-up, with a last radiographic follow-up occurring within 3 to 39 weeks (median, 12). Information about lameness, ROM, and bone healing at last radiographic follow-up was available for 23 of 25 (92%), 15 of 25 (60%), and 25 of 25 (100%) dogs, respectively. At last radiographic follow-up, the median lameness score was 1 (minimally detectable lameness); five of 15 (33.3%) dogs had reduced elbow ROM, and bone healing was complete in 10 of 25 (40%) dogs.

## 3.5 | Long-term outcome

Long-term outcome (range, 12-96 months; median, 36) was available for 31 of 112 (27.7%) dogs and was considered excellent in 26 of 31 (83.9%), very good in two of

31 (6.5%), good in one of 31 (3.2%), and fair in one of 30 (3.3%) dogs. Among those dogs that did not have an excellent outcome, only one had a prior complication. Four dogs with unilateral HCF, of which two had suffered a complication, were reported to be lame in the long-term; however, the outcome was considered excellent in three of these four dogs. Four dogs with unilateral HCF, of which one had a complication and two were reported to be lame, were reported to be receiving anti-inflammatory drugs long-term; however, the owner-assessed outcome, again, was considered excellent in three of them.

### 3.6 | Complications

There were 35 complications from 115 HCF repaired, providing an overall complication rate of 30%, with one catastrophic, 33 major, and one minor complication. Thirty-three of 35 complications were perioperative, one complication was short term, and one complication was long term. Eighteen complications in 115 (15.7%) HCF were implant related, 12 of 115 (10.4%) complications were infection related, four of 115 (3.4%) complications were intraoperative, and one of 115 (0.9%) complication was categorized as other. The four HCF with intraoperative complications were immediately revised by repositioning of implants, two because of intra-articular transcondylar screws, one because of an over-long lateral K-wire, and one because of reposition of an epicondylar screw.

Among the 18 implant-related complications, one dog was euthanized and counted as a catastrophic complication, six of 18 dogs required revision surgery, six of 18 dogs required an explantation, and five of 18 dogs were treated conservatively. All 12 infection-related complications required antibiotics; 11 of 12 required antibiotics as a sole treatment, and one of 12 required antibiotics in conjunction with explantation. The minor complication was a seroma that resolved without treatment.

As previously described, bilateral HCF (three dogs, six fractures) and HCF with both implant-related and non–implant-related complications (n = 3) were excluded. Implant-related complication rates in the plate, epicondylar screw, and epicondylar K-wire groups were four of 64 (6.3%), two of 15 (13.3%), and nine of 28 (32.1%), respectively. Overall, implant-related complications in unicondylar HCF repaired with a plate ± an additional implant occurred in one of 38 (2.6%) HCF, one of 35 (2.9%) in lateral HCF and zero of three (0%) in medial HCF. Implant-related complications in bicondylar HCF repaired with a plate ± an additional implant occurred in two of 20 (10%) fractures bilaterally plated, zero of four (0%) fractures medially plated, and one of two (50%) fractures laterally plated (Table 3). Only four of 64 (6.2%) plate constructs had implant-related complications, of which two were locking, and two were nonlocking. Infection-related complications occurred with nine of 66 (16.2%) plates, two of 15 (13.3%) infection-related complications occurred with screws, and no (0/26) infection-related complications occurred with K-wires (Table 3).

There was no association between fracture morphology and complication type ($P = .507$). An association was found between epicondylar fixation and complication type; epicondylar plate fixation had a lower rate of implant-related complications compared with other methods of repair not including a plate ($P = .009$).

French bulldogs and the spaniels group did not differ in their risk of complication development ($P = .326$). Age (<1 vs ≥1 year) was not associated with complication development ($P > .99$). There was no association between fracture reconstruction and complication type ($P = .223$).

The 4.5-mm transcondylar screw implant had the lowest implant-related complication rate at 5.7% (2/35)

**TABLE 3** Complications associated with epicondylar fixation methods

| Epicondylar fixation method | Total fractures, n | Implant-related complications, n | Implant-related complications, % | Infection-related complications, n | Infection-related complications, % |
|---|---|---|---|---|---|
| K-wire | 28 | 9 | 32 | 0 | 0 |
| Screw | 15 | 2 | 13 | 2 | 13 |
| Plate | 64 | 4 | 6 | 9 | 14 |
| Unicondylar FLP | 35 | 1 | 3 | 5 | 14 |
| Unicondylar FMP | 3 | 0 | 0 | 0 | 0 |
| Bicondylar FBP | 20 | 2 | 10 | 4 | 20 |
| Bicondylar FLP | 2 | 1 | 50 | 0 | 0 |
| Bicondylar FMP | 4 | 0 | 0 | 0 | 0 |

Abbreviations: FBP, fracture bilateral plate; FLP, fracture lateral plate; FMP, fracture medial plate.

**TABLE 4** Complications associated with transcondylar repair methods

| Transcondylar fixation method | Total fractures, n | Implant-related complications, n | Implant-related complications, % | Infection-related complications, n | Infection-related complications, % |
|---|---|---|---|---|---|
| **4.5-mm screw** | 35 | 2 | 6 | 6 | 17 |
| **3.5-mm screw** | 17 | 3 | 18 | 1 | 6 |
| **2.7-mm screw** | 24 | 3 | 13 | 1 | 4 |
| **2.4-mm screw** | 10 | 2 | 20 | 2 | 20 |
| **2.0-mm screw** | 15 | 4 | 27 | 1 | 7 |
| **Cortical screw** | 93 | 16 | 17 | 10 | 11 |
| **Shaft screw** | 8 | 0 | 0 | 1 | 13 |
| **Medial screw** | 14 | 1 | 7 | 1 | 7 |
| **Lateral screw** | 91 | 14 | 15 | 10 | 11 |
| **Positional screw** | 11 | 2 | 18 | 2 | 18 |
| **Lag screw** | 80 | 11 | 14 | 8 | 10 |
| **Washer** | 50 | 8 | 16 | 4 | 8 |
| **No washer** | 57 | 7 | 12 | 7 | 12 |

compared with 3.5-mm transcondylar screw at 17.6% (3/17), 2.7-mm transcondylar screw at 12.5% (3/24), 2.4-mm transcondylar screw at 20% (2/10), and 2-mm transcondylar screw at 26.7% (4/15). Similarly, none (0/8) of the shaft screws had implant-related complications compared with a 17.2% (16/93) implant-related complication rate with cortical screws. Implant-related complications with lag screws were similar to implant-related complications with positional screws, 11 of 80 (13.8%) and two of 11 (18.1%), respectively. Implant-related complications were similar with or without a washer, eight of 50 (16%) vs seven of 57 (12.3%), respectively. The two intra-articular screws were transcondylar screws placed from medial to lateral for medial HCF. Implant-related and infection-related complications for transcondylar screws were 14 of 91 (15.4%) and 10 of 91 (11%), respectively, for lateral screws and one of 14 (7.1%) and one of 14 (7.1%), respectively, for medial screws (Table 4).

## 4 | DISCUSSION

This study is the largest in more than 25 years to document the prevalence and risk factors for HCF in dogs. Breed predisposition was confirmed for spaniel breeds and detected for French bulldogs. A predisposition of spaniel breeds to HCF has been linked to HIF[9]; however, the pathogenesis of HCF in French bulldogs remains unknown. Among the fractures that had contralateral limb imaging, only 16 had a HIF, and none were French bulldogs; however, the prevalence of bilateral HIF in non-spaniel breeds is only 33%.[30] Rorvik[6] used a case–control population to calculate the prevalence of HCF,[6] and spaniel breeds were not identified as being at risk of HCF; however, the study population was from Norway in the early nineties, so breed distribution and regional breed genetics may explain the difference seen. The Rorvik[6] study is the only other report of French bulldogs being at risk; however, there were only four French Bulldogs with HCF, and care must be taken when reviewing the data because of the small group sizes.

Fracture morphology distribution was similar to that previously reported,[1,3–7] with about two of three HCF being lateral HCF. In the current study, French bulldogs had a different predisposition of fracture configuration with a higher rate of medial HCF compared with other dogs. The cause is unclear; however, it has been has determined that medial HCF occur due to the interaction between ulna and humerus, whereas the radial loading is implicated in lateral HCF.[2] The chondrodystrophic conformation of the elbow in French bulldogs may influence loading patterns and hence fracture configuration. The other medial HCF reported in the present study occurred predominantly in chondrodystrophic dogs: two Cavalier King Charles spaniels, one pug, and one crossbreed dog.

The median age of dogs with HCF was 5 months, which is in line with previous studies.[4,6] Five months is after the expected fusion of the two centers of ossification of the humeral condyle (lateral and medial) at 85 days (3 months).[31] Fusion to the distal humeral metaphysis occurs by 5.5 to 6 months[31]; however, the epicondylar fracture is typically proximal to the distal humeral physis. Therefore, the risk of HCF from being skeletally immature is probably not due to physeal/cartilaginous weakness.

Implant-related complications were significantly lower with plate constructs than with epicondylar screw(s) ± epicondylar K-wire(s) or with epicondylar K-wire(s) alone, which is in line with a previous study on lateral condylar fractures.[22] However, in that study epicondylar screws were analyzed in the same group as plates, whereas we separately analyzed epicondylar screw and epicondylar plates. In a biomechanical evaluation of plate vs lag screw only fixation of oblique distal fibular fractures in man,[32] constructs stabilized with one lag screw were weaker compared with plated constructs for both lateral bending and rotational stiffness.

Sixty-nine percent of dogs had reduced elbow ROM at the first follow-up, which decreased to 33% at last radiographic follow-up; reduced ROM is not unexpected after humeral articular fracture repair.[33] Despite reduced joint mobility, only minimally detectable lameness was present at first and last follow-ups, and the outcome was excellent in 87% of dogs according to the long-term CBPI and questionnaire results. Previous literature has reported fair and poor limb function in 57% of dogs[1] as well as 36% mild occasional lameness and 18% moderate to severe lameness.[4] Unfortunately, the influence of breed, complications, and ASD on long-term outcome could not be determined because questionnaire response was low and most dogs had an excellent outcome.

This study is limited by its retrospective nature, which may have introduced selection bias. The use of the age at the final record date for the nonfracture dogs may have biased the nonfracture dogs toward older age. The decision to include only breeds with six or more HCF was based on the experiences reported in previous publications rather than on a formal statistical calculation. However, altering this cutoff may have allowed entry of additional or fewer breeds to the study. There was no randomization of repair technique or prospective measurement of outcome indices. Postoperative imaging studies were based on orthogonal radiographic projections of the elbow, and positioning can be compromised by the reduced ROM of the joint posttrauma and postsurgery, which could alter radiographic interpretation. The owner questionnaire response was low (26.8%) but this is in line with other studies in which long-term outcomes have been evaluated. This is a report of a single-center study reflecting local breed and genetic bias; this report describes prevalence within a population of dogs that were referred for specialist care not prevalence within the total canine population. Nonetheless, this report describes the most robust prevalence and risk study in which HCF in dogs has been evaluated to date. In summary, French bulldogs and spaniel breeds were predisposed to HCF, and medial HCF were more common in French bulldogs. Application of an epicondylar plate was associated with reduced complications and is recommended for HCF surgery.

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## CONFLICT OF INTEREST

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

## ORCID

*Richard L. Meeson* https://orcid.org/0000-0002-8972-7067

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## SUPPORTING INFORMATION

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

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