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CLINICAL RESEARCH

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Bi-oblique dynamic promial ulna osteotomy: Effect of location on change in angle of the proximal ulna segment

Jessica P. Farrugia BVSc, DVM, MANZCVS (Small Animal Surgery)[1] | **Samuel R. Snelling FANZCVS (Small Animal Surgery)**[1] | **John M. Morton BVSc (Hons), PhD, MANZCVS (Veterinary Epidemiology)**[2]

[1]Advanced Vetcare, Melbourne, Victoria, Australia

[2]Jemora Pty Ltd, Geelong, Victoria, Australia

Correspondence
Jessica P. Farrugia, Advanced Vetcare, 26 Robertson Street, Kensington, Victoria 3031, Australia.
Email: jessica.farrugia@advancedvetcare.com.au

Abstract

Objective: To assess whether the location of a bi-oblique dynamic proximal ulna osteotomy (BODPUO) affects the change in angle of proximal ulna tilt from the time of surgery to 6–8 weeks postoperatively.

Study design: A retrospective, single cohort study.

Sample population: A total of 45 elbows from 41 dogs were enrolled in the study.

Methods: Immediate postoperative and 6–8 week postoperative radiographs were reviewed to determine the location of the BODPUO in relation to the total ulna length and the change in proximal ulna angle achieved postoperatively. The median duration of follow-up (final postoperative radiographs) was 6 weeks with a minimum and maximum of 4 and 10 weeks, respectively. Regression models were used to generate prediction intervals to describe the change in angle that would be expected following a BODPUO in individual future cases, based on the location of the ulna osteotomy.

Results: A total of 41 elbows (one per patient) were used in the statistical analyses. A more proximal BODPUO resulted in a larger postoperative increase in the proximal ulna angle. The most proximal osteotomy, at 26% of the total ulna length, achieved the greatest change in proximal ulna tilt of 18°. For a particular location of a BODPUO in future cases, the change in angle achieved may depend in part on the initial proximal ulna angle (IPUA).

Conclusion: There was a strong relationship between the location of a BODPUO and the change in angle of the proximal ulna postoperatively, with more proximal ulna osteotomies achieving the largest change in proximal ulna tilt.

Clinical significance: These findings provide objective data on the change in proximal ulna tilt for varying locations of a BODPUO.

Abbreviations: BODPUO, Bi-oblique dyanmic proximal ulna osteotomy; CI, confidence interval; CT, computed tomography; FPUA, final proximal ulna angle; IPUA, Initial proximal ulna angle; MOS, Modified outerbridge score.

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1 | INTRODUCTION

Elbow dysplasia is a developmental disease, most commonly seen in young, large-breed dogs.[1] Asynchronous growth between the radius and ulna results in supraphysiological overload of the medial joint compartment and subsequent fatigue and microfracture of the underlying subchondral bone.[1] Translation of the joint contact area away from the center of the articular surface can ultimately lead to fragmentation of the medial coronoid process.[1,2] A bi-oblique dynamic proximal ulna osteotomy (BODPUO) is predominantly performed in dogs between 5 and 12 months of age presenting with moderate to severe medial compartment disease in an attempt to unload the medial joint compartment, improve elbow congruity and minimize osteoarthritis development.[3] Over time, technique refinement has progressed from a transverse and short oblique osteotomy to a BODPUO. Reported benefits of BODPUO include minimizing the morbidity, healing times, caudal tilting, and varus rotation of the free proximal ulna segment.[1,3] Complications reported for proximal ulna osteotomies include excessive caudal and varus tilting, luxation of the radial head, swelling, synostosis between the radius and ulna, inadvertent radial osteotomy and non-union or delayed union of the proximal ulna osteotomy.[3,14] In the largest cohort study to date assessing 120 elbows, an overall minor complication rate of 12% was reported for BODPUO with no patients experiencing any major complications.[8] Recently, Danielski et al. reported higher overall complication rates associated with this procedure with 22.2% of patients experiencing delayed unions and 2.2% having excessive caudal tiling of the proximal ulna segment.[14]

Imaging studies assessing elbow incongruity before and after a BODPUO have demonstrated a lack of distal axial translation of the proximal ulna segment to realign the radial and ulna joint surfaces. Rather, rotation in three planes occurs at the joint surface level with caudal tipping of the osteotomy.[1] A computed tomography (CT) study by Fitzpatrick et al. assessing the radioulnar joint interface following a BODPUO demonstrated that there was divergence of the lateral coronoid region of the radial incisure of the ulna away from the radial head. Additionally, rotation occurred that was centered at the tip of the medial coronoid process around the radial head, resulting in a reduction of the concentration of forces at the medial coronoid process.[4] This finding was corroborated in a cadaveric biomechanical study by Krotscheck et al., in which proximal ulnar osteotomies successfully reduced mean and peak contact pressures when positive radioulnar incongruency was present.[5] A recent CT and bi-planar, fluoroscopic kinematographic study in a Labrador Retriever following a BODPUO found that dynamic radioulnar incongruency was unaffected by the procedure. Additionally, there was incomplete resolution of static radioulnar incongruency, mirroring previous reports by Bottcher et al.[1,6] Benefits of this procedure are more likely attributable to an increase in the humeroulnar joint contact area, rather than realignment of the radioulnar joint surfaces.[6]

It is accepted that a BODPUO performed above the interosseous ligament will achieve greater motion of the osteotomized ulna segment.[7] Previous studies have also demonstrated the beneficial effects of performing a BODPUO between the proximal and mid-third of the radius to achieve a more homogenous distribution of forces across the ulna joint surface.[4] However, current recommendations within the literature on the optimal location to perform a BODPUO are varied and poorly defined. Reported recommendations for where to perform a proximal ulna osteotomy include a mean of 39%, 30% and 33% of the total ulna length, at the junction between the proximal and mid-third of the radius and 3 cm distal to the elbow joint.[4,7–9] To the best of our knowledge, there is currently no objective data describing changes in proximal ulna tilt achieved with respect to varying locations of a BODPUO. The objective of this study was to assess whether the proximity of a BODPUO affects the change in angle of proximal ulna achieved from the time of surgery to 6–8 weeks postoperatively. A further aim was to generate prediction intervals to describe the likely change in angle that would be expected following a BODPUO in an individual future elbow based on the relative point of the ulna osteotomy. We hypothesized that the more proximal a BODPUO is performed, the greater the degree of resultant proximal ulna tilt.

2 | MATERIALS AND METHODS

Elbows from patients that had a BODPUO performed from a single referral hospital with surgery from January 1, 2016 to December 31, 2023 were enrolled in a retrospective single cohort study.

To be eligible for enrolment in the study, cases were required to have been diagnosed with moderate to severe medial compartment disease by radiographic and arthroscopic assessment of the elbow joint. Moderate to severe medial compartment disease was defined as elbows with fragmentation of the medial coronoid process, medial humeral condylar osteochondrosis dissecans lesion and/or “kissing lesions” on the medial humeral condyle. All patients had a modified Outerbridge score (MOS) of 2 and above, except for one patient who did not have an assigned MOS. The final decision to proceed to a BODPUO was made based on the severity of medial compartment disease present on arthroscopic assessment of the elbow joint. Cases were ineligible for enrollment if a BODPUO was performed for reasons unrelated to medial compartment disease including ununited anconeal process or if the patient had concurrent angular limb deformities. Eligible patients with incomplete clinical follow-up or poor postoperative radiographic projections (oblique or rotated views) were excluded from the study. All other eligible elbows were enrolled.

2.1 | Surgery and image analysis

All patients had arthroscopic examination of the affected elbow and debridement of the medial compartment prior to a BODPUO being performed. A standard caudolateral approach to the proximal ulna was performed with incision of the deep fascia and separation of the flexor carpi ulnaris and extensor carpi ulnaris.[8] The periosteum was elevated from the ulna and the radius was protected with Hohmann retractors. The location and trajectory of the osteotomy was performed at the surgeon's discretion and no patients had elevation of their interosseous ligament. Immediate postoperative radiographs were performed and a modified Robert-Jones bandage was applied prior to anesthetic recovery. Patients were hospitalized overnight for supportive care and the Robert-Jones bandage was removed prior to discharge. All patients were discharged the following day; however, information regarding the time of discharge was not available for one patient. Strict rest was recommended for a minimum of 6 weeks following surgery with gentle leash walking from 6 to 8 weeks postoperatively. Postoperative radiographs were generally performed between 6 and 8 weeks following surgery (for 85% or 34/40 elbows, the interval was from 5.6 to 8.4 weeks), with a minimum and maximum time frame of 4 weeks and 10 weeks, respectively (mean = 6.8 weeks; median = 6 weeks).

The location of the BODPUO was measured on lateral immediate postoperative radiographic projections using a DICOM online imaging platform (Purview Medical Cloud, Annapolis, Maryland). The length of the ulna was measured from the distal aspect of the styloid process to the proximal aspect of the caudal olecranon tuber. The position of the ulna osteotomy was measured from the proximocaudal aspect of the ulna osteotomy to the proximocaudal aspect of the olecranon tuber (Figure 1). The position of the ulna osteotomy was then calculated as a percentage of the total ulna length. A vector software program (Adobe Photoshop, San Jose, California) was used to superimpose the lateral radiographs obtained immediately and 6–8 weeks post-surgery. The radius was used as a calibration marker to accurately superimpose the two images and the opacity of the 6–8 week postoperative radiograph was adjusted between 40% and 70% to allow for both the immediate and 6–8 week postoperative projections to be viewed simultaneously. The superimposed images were imported into an orthopedic planning software (VPOP imaging, Shrewsbury, UK) to compare the change in tilt of the proximal ulna in the immediate postoperative radiographs to the 6–8 week postoperative radiographs. The proximal radial joint orientation line was applied to standardize the measurements and a line perpendicular to the orientation line was drawn. On each of the immediate postoperative and 6–8 week postoperative projections, a line was drawn from the caudoproximal aspect to the most cranioproximal aspect of the olecranon tuber. These lines were extended to intersect with the perpendicular reference point and the resulting angle was measured (Figure 2A,B). The change in ulna tilt achieved was calculated as the final proximal ulna angle (FPUA) (6–8 weeks postoperative measurement) minus the IPUA (immediate postoperative measurement). A larger negative value of change in proximal ulna angle indicated a greater change in angle.

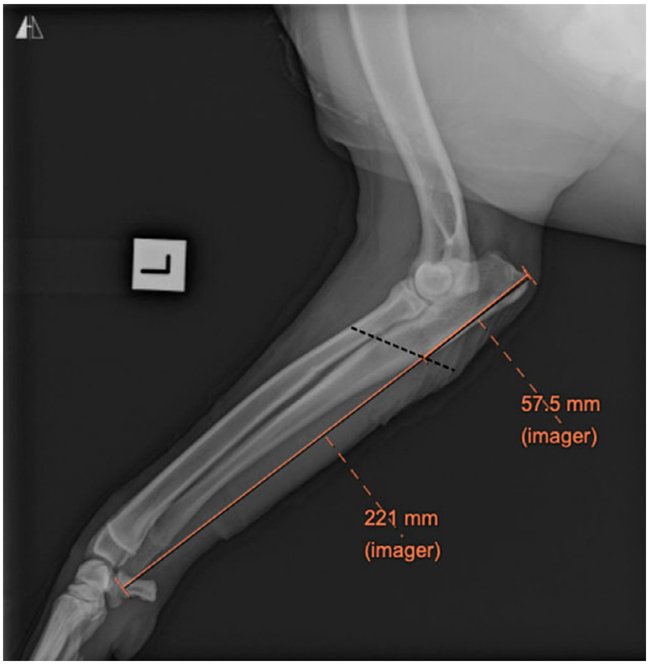

FIGURE 1 Measurement of the location of the ulna osteotomy as a percentage of the total ulna length. The broken line denotes the location of the ulna osteotomy. The formula of the calculation was (total length of the ulna)/(position of the ulna osteotomy) $\times$ 100. In Figure 1, this equates to (57.5/221) $\times$ 100 = 26.02%.

Immediate postoperative radiographs were used to assess the IPUA instead of the preoperative radiographs. A significant portion of the preoperative radiographs in the data set did not include the entire length of the radius. This prohibited the radius from being used as a calibration marker and superimposition of the preoperative and follow-up radiographs to standardize measurements of the proximal radial joint orientation line.

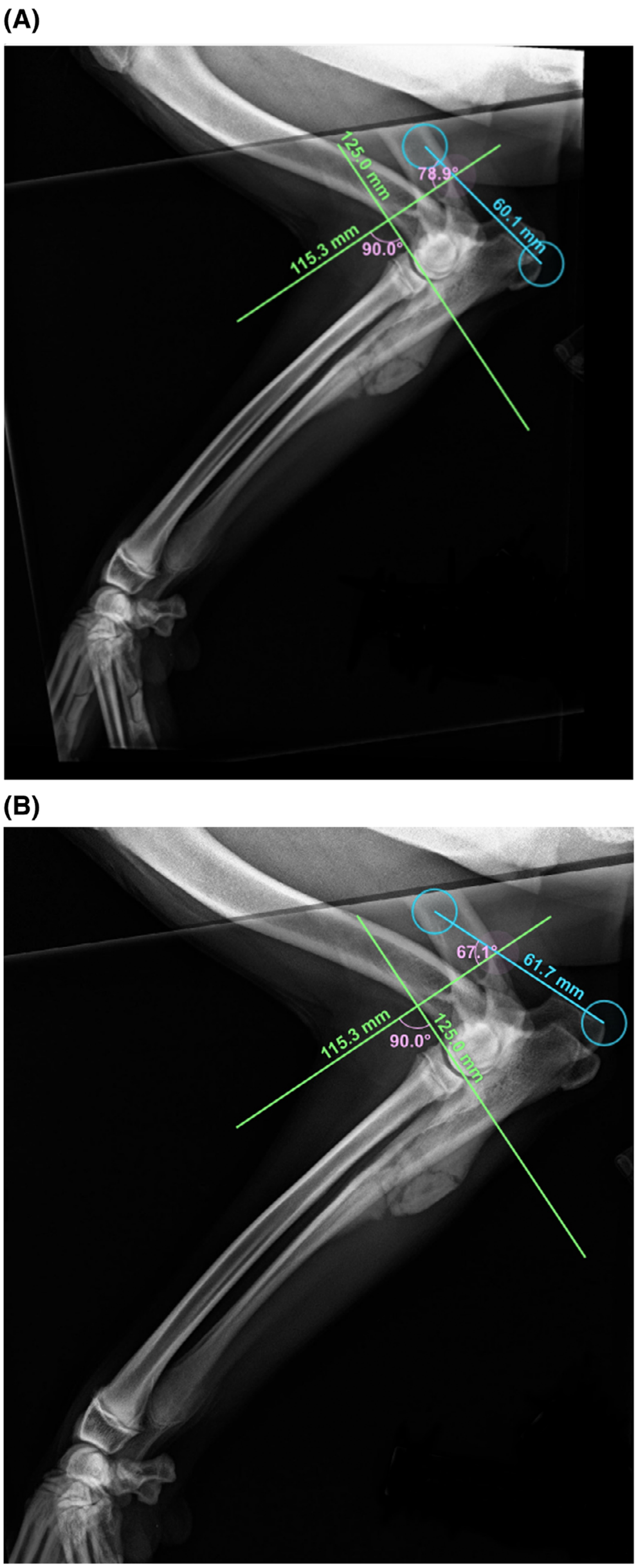

FIGURE 2 (A) Measurement of the immediate postoperative proximal ulnar angle (initial proximal ulnar angle) on the superimposed radiographs using the proximal radial joint orientation line as a reference point. (B) Measurement of the 6–8 week postoperative proximal ulnar angle (follow-up proximal ulnar angle) on the superimposed radiograph using the proximal radial joint orientation line as a reference point.

To minimize variability in the data set, the immediate postoperative radiographs were measured instead. The mean difference between the preoperative and immediate postoperative radiographs (measured without superimposition) for the proximal ulna angle was 0.86°. While it is possible that these minor changes could be due to proximal ulna kick-back following the BODPUO, the minimal variability between the IPUA measurements supports the use of the immediate postoperative radiographic projections to obtain this value.

The craniocaudal angle of the osteotomy was assessed from the lateral, immediate postoperative radiographic projections. Additionally, the length of the ulna osteotomy was measured from the same radiographic projection, starting from the most proximocaudal aspect of the osteotomy to the most craniodistal aspect of the osteotomy.

2.2 | Statistical analysis

Distributions of variables are described using means, SD and minimum and maximum values.

The association between the relative point of the ulna osteotomy and the change in angle of the proximal ulna (FPUA minus IPUA) was assessed using generalized linear models fitted using the -glm- command in Stata (version 18, StataCorp, Texas). Observed changes in angle ranged from −18 to 0°. For analyses, these were instead expressed as the corresponding positive values (thus ranging from 0 to +18°), and the Poisson distribution with log link was used. This ensured that all fitted values were ≥0°, which was appropriate as an ulna osteotomy would not cause the ulna to angle less. To ensure elbows were statistically independent, for each of the four dogs with two elbows enrolled, one elbow was chosen for inclusion in analyses using computer-generated random numbers. Thus, 41 elbows were used in the final analyses.

The shape of any relationship between the relative point of the ulna osteotomy and the change in angle was first assessed using 44 fractional polynomials of the relative point of the ulna osteotomy assessed in generalized linear models as described above. All single and two-dimension fractional polynomials of the powers −2, −1, −0.5, 0, 0.5, 1, 2, and 3 were assessed (44 in total) and each of the best-fitting single and two-dimension fractional polynomials identified based on model deviances. The best-fitting single and two-dimension fractional polynomials were each compared to the linear term by visual assessment of component-plus-residual plots, and the most appropriate term was selected for inclusion in the final regression model. Component-plus-residual plots for the best-fitting single and two-dimension fractional polynomials indicated that the relationship between the relative point of the ulna osteotomy and change in angle is close to linear, and a linear relationship when the log link is used was assumed. After fitting the model, fitted means for change in angle and associated pointwise 95% CIs were generated for relative points of the ulna osteotomy for each integer from 26% to 48% using Stata's -margins- command. Fitted means and 95% CI limits were multiplied by −1 so that they were then on the same scale as the original data. The predictive power of the model was summarized as the correlation between fitted and observed changes in angle across all 41 elbows.[10]

We also used the same regression model to generate prediction intervals. Whereas 95% CI limits for fitted means provided information about the precision of those estimated means, prediction intervals provided information about the range of likely values for change in angle for a single future individual elbow based on the relative point of the ulna osteotomy used for that forelimb. Thus, prediction intervals are highly relevant in a clinical setting where the outcomes for individuals are the focus. Prediction intervals were generated using the ciTools package (version 0.6.1[11] in R, version 4.4.0).[12] The same generalized linear model was fitted to the same data, both as described above, and 95% prediction intervals generated using a parametric bootstrap process then taking quantiles on the bootstrapped data produced for each observation. A total of 20 000 simulations were used.

In preliminary analyses, we also explored whether the effect of the relative point of the ulna osteotomy on change in ulna angle depends, in part, on the initial angle. We postulated that, at any particular relative point of the ulna osteotomy, changes in proximal ulna angle are larger when the IPUA is closer to 90°, due to greater force exerted by the triceps on the olecranon in a cranial direction, relative to a smaller IPUA. We used the same model as described above but, in addition to the relative point of the ulna osteotomy, we simultaneously also fitted IPUA and the term for the interaction between relative point of the ulna osteotomy and IPUA, to model the effects of relative point of the ulna osteotomy on change in angle at different initial angles. Any relationship between IPUA and change in angle was assumed to be linear based on the same process as described above for assessing the shape of any relationship between the relative point of the ulna osteotomy and change in ulna angle. These analyses were considered preliminary because our method for measuring the IPUA was standardized relative to the proximal radial joint orientation line. These relative changes in angle may not be an accurate representation of the true IPUA.

The association between the craniocaudal angle of the osteotomy and the change in angle of the proximal ulna was assessed using the same methods as described above for the relative point of the ulna osteotomy. To adjust for any confounding effects, the relative point of the ulna osteotomy was simultaneously fitted as a fixed effect. The association between the osteotomy length and the change in angle of the proximal ulna was assessed in the same way.

3 | RESULTS

A total of 41 dogs had at least one elbow that met the inclusion criteria, with four of these dogs having had bilateral ulna osteotomies performed (45 elbows in total). Two of the 41 dogs had staged, bilateral BODPUPO procedures. However, for each of these dogs, only one elbow met the inclusion criteria. A further 12 of these 42 dogs had bilateral BODPUO performed in a single procedure. For four of these 12 cases, both elbows met the inclusion criteria. A total of 16 breeds or crossbreeds were represented in the study, with the majority of dogs being either Labrador Retrievers ($n = 16$) or Golden Retrievers ($n = 7$). Other breeds represented in the study were Rottweilers ($n = 3$), Labrador crosses ($n = 2$), Staffordshire Bull Terrier ($n = 2$), Kelpie cross ($n = 1$), Australian Shepherd ($n = 1$), Newfoundland ($n = 1$), Alaskan Malamute ($n = 1$), Border Collie ($n = 1$), Rhodesian Ridgeback ($n = 1$), Bullmastiff ($n = 1$), Bullmastiff cross ($n = 1$), Shar Pei ($n = 1$), Australian Cattle Dog cross ($n = 1$) and a Japanese Spitz ($n = 1$). The majority were large breed dogs with 78% (32/41) weighing between 21 and 40 kg at the time of surgery. Patient weights ranged from 8.6 to 47.2 kg, with a mean and median weight of 28.6 kg and 28.8 kg, respectively. A total of 54% of the cohort (22/41) were male and 46% (19/41) were female. A total of 80% of patients (33/41) were between 5 and 12 months of age at the time of surgery, with ages ranging from 5 to 31 months (mean = 11.0 months; median = 10 months). Surgical procedures were performed by three registered surgical specialists and two veterinarians limited to the practice of surgery.

3.1 | Effects of relative point of the ulna osteotomy on change in angle of the proximal ulna

Descriptive statistics for the relative point of the ulna osteotomy and proximal ulna angles for the 41 elbows are shown in Table 1. Observed changes in angle and fitted means for change in angle, both by relative point of the ulna osteotomy, are shown in Figure 3.

TABLE 1 Descriptive statistics for 41 canine elbows following a BODPUO.

	Proximity of the osteotomy (%)[a]	Initial angle of the proximal ulna (°)[b]	Final angle of the proximal ulna (°)[c]	Change in angle of the proximal ulna (°)[d]
Minimum	26.02	58.7	50.0	−18.0
10th percentile	27.5	65.0	56.3	−16.8
25th percentile	30.0	69.7	61.7	−12.5
50th percentile	35.2	74.8	67.1	−8.4
75th percentile	40.6	81.5	71.8	−3.4
90th percentile	43.8	86.5	79.5	−1.7
Maximum	49.0	93.0	93.0	0.0

Abbreviation: BODPUO, bi-oblique dynamic proximal ulna osteotomy.
[a]Location of the ulna osteotomy expressed as a percentage of the total ulna length.
[b]From views taken immediately postoperatively.
[c]From views taken 6–8 weeks postoperatively.
[d]A negative value for change indicates an increase in angle.

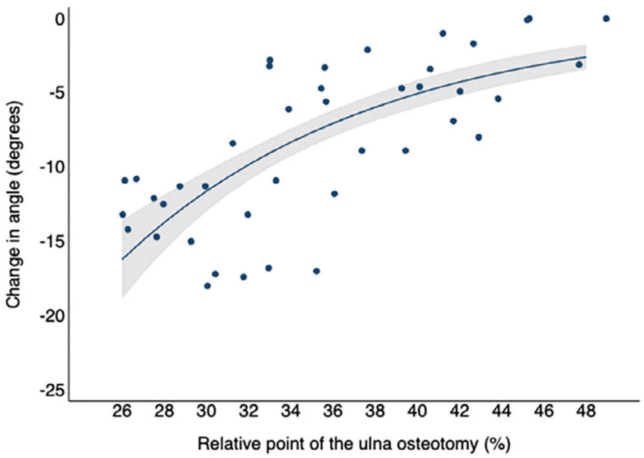

FIGURE 3 Observed changes in angle for 41 elbows (markers) and fitted means from a generalized linear regression model of change in angle (line), both by relative point of the ulna osteotomy. Gray zone indicates pointwise 95% CIs for fitted means. A negative value for change indicates an increase in angle.

Compared to more distal osteotomies (i.e., relative point of the ulna osteotomy closer to 46%–48%), more proximal osteotomies (i.e., relative point of the ulna osteotomy closer to 26% to 28%) resulted in larger increases in angle (i.e., more negative values for change in angle; Table 1).

The correlation coefficient for the association between fitted and observed changes in angle across all 41 elbows was 0.73, indicating that the model with just relative point of the ulna osteotomy had good predictive power. However, assuming measurement errors were minimal, the scatter of observed values in Figure 3, along with this correlation coefficient indicates that there are additional determinants affecting change in angle of the proximal ulna.

3.2 | Prediction intervals

Prediction intervals generated for the expected change in angle of the proximal ulna relative to the location of the ulna osteotomy for future individual elbows that undergo BODPUO are shown in Figure 4. The predicted values for future elbows varied considerably. For example, for BODPUO's that are to be performed at 36% of the total ulna length, for 95% of cases, the change in angle is predicted to be between −2 and-12°. This indicates that for an osteotomy performed at a specific location on the ulna, there is a wide range of changes in angle of the proximal ulna that can be expected postoperatively. Prediction intervals were wider when the ulna osteotomy is performed more proximally (i.e., closer to 26%–28% of the total ulna length) indicating that more variation in change in angle of the proximal ulna is expected in future cases when the ulna osteotomy is performed more proximally.

3.3 | Interaction between relative point of the ulna osteotomy and IPUA

In the preliminary analyses, we also explored whether the relationship between relative point of the ulna osteotomy and change in angle of the proximal ulna varies depending on the IPUA. Our results were consistent with our postulate that for any particular relative point of the ulna osteotomy, changes in ulna angle were larger when the IPUA was closer to 90°. For example, for an ulna osteotomy performed at 26% of the total ulna length, fitted mean changes in angle for IPUA of 60, 70, 80 and 90° from the regression model were, respectively, −10° (95% CI: −6 to −14°), −14° (95% CI: −11 to −17°), −19°

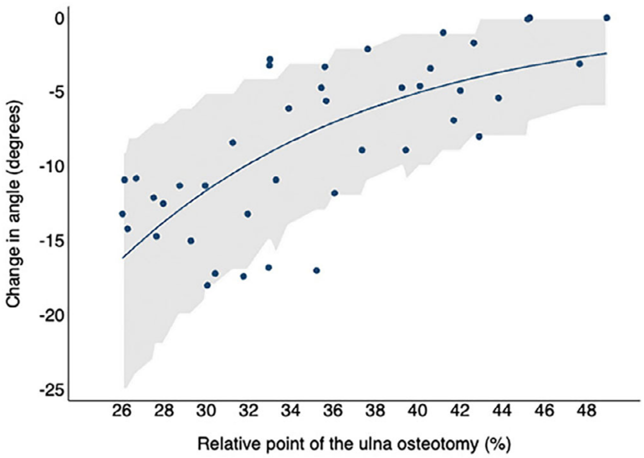

FIGURE 4 This shows 95% prediction intervals (gray zone) for expected change in angle of the proximal ulna relative to the location of the ulna osteotomy. Line indicates fitted means. A negative value for change indicates an increase in angle.

(95% CI: −15 to −23°), and −26° (95% CI: −17 to −35°). Thus, changes in ulna angle were larger when the IPUA was closer to 90°.

Therefore, if these preliminary findings are confirmed in studies where the true IPUA are measured, we would conclude that for any BODPUO location, patients with an IPUA closer to 90° would be expected to achieve a larger change in IPUA on average relative to those with an IPUA closer to 60°.

3.4 | Changes in radial length from immediate postoperative to follow-up

The change in radial length from the immediate postoperative to the follow-up postoperative radiographs could be determined for 27 of the 41 elbows. For the remaining 14 elbows, the length of the radii could not be accurately measured as calibration markers had not been included in both the immediate and follow-up radiographic projections. The mean of the differences (follow-up postoperative radiographs minus immediate postoperative radiographs) was +2.37 mm (SD 3.9 mm; range −2.0 to +14.1 mm). The two largest increases (10.6 and 14.1 mm) were in dogs that were 5 months of age at the time of surgery.

3.5 | Association between craniocaudal angle and change in angle

Craniocaudal angle of the ulna osteotomy was available for 40 of the 41 elbows and was measured on immediate postoperative radiographs. These varied widely (from 24.4 to 74.8°; mean 50.3; SD 12.3°). After adjusting for the relative point of the ulna osteotomy, the estimated increase in tilt for each 10° increase in craniocaudal angle was only 0.8° (95% CI: −0.1 to 1.7°).

3.6 | Association between osteotomy length and change in angle

Osteotomy length was available for 35 of the 41 elbows. These varied widely (from 8 to 36 mm; mean 20.7; SD 7.0 mm). After adjusting for relative point of the ulna osteotomy, the estimated change in tilt for each 10 mm increase in osteotomy length was virtually 0 (estimated decrease 0.03°; 95% CI: −1.5 to +1.5°).

4 | DISCUSSION

Our results demonstrate that the more proximal the location of an ulnar osteotomy (e.g., 26%–28% of the total ulna length), the greater the change in the proximal ulna angle postoperatively. Additionally, osteotomies performed more distally from 40% to 49% of the total length of the ulna resulted in minimal to no change on average in the angle of the proximal ulna postoperatively (4.6° and 0°, respectively). The minimal postoperative tilt of the proximal ulna segment when osteotomies are performed more distally is attributable to strong tethering of the radius to the ulna by the interosseous ligament, preventing unrestricted motion of the proximal ulna segment.[7,8,13] These findings align with results from the radiographic study of Kranz et al., in which ulnar osteotomies performed at 30% of the total length of the ulna had significantly more caudal displacement of the proximal ulna segment compared with osteotomies performed at 50% of the total ulna length.[7]

This study provides objective information regarding the change in proximal ulna tilt achieved for varying locations of a BODPUO performed between 26% and 49%. Most of the current literature reports on the clinical and biomechanical improvements in joint contact patterns achieved with an ulnar osteotomy performed arbitrarily within the proximal third of the total ulna length.[4,7–9] Fitzpatrick et al. reported on 26 cases, in which a BODPUO was performed at the junction of the proximal to middle third of the radius. There was no statistically significant changes in the radioulnar step when examining postoperative CT findings. Rather, rotation of the proximal ulna segment occurred that was centered at the medial coronoid process, offloading forces from the medial compartment.[4] Similar results were mirrored by

Bottcher et al. for dynamic proximal ulnar osteotomies performed approximately 3 cm distal to the radial head, in which realignment of the radioulnar joint surface did not occur postoperatively. Instead, uncoupling of the medial compartment occurred increasing the radioulnar subchondral joint space width and creating a more uniform joint contact pattern.[1] Additionally, in a recent case report, BODPUO performed in the proximal third of the ulna reduced the concentration of forces at the lateral aspect of the medial coronoid tip by 68% and increased the overall humeroulnar joint contact area at the medial coronoid process by 10.5% postoperatively.[6] Given that the location of the ulna osteotomy has a good predictive power (correlation coefficient of 0.73) for determining the degree of proximal ulna tilt achieved postoperatively, this evidence provides a basis for determining if a greater change in angle of the proximal ulna results in a more homogenous distribution of forces across the ulna joint surface. This information is an important step for identifying an ideal zone for BODPUO, based on future, long-term clinical follow-up. Once this zone is established, the surgeon can use the described relationship between the location of the ulna osteotomy and the change in proximal ulna angle for preoperative planning to achieve a more precise change in proximal ulna tilt.

Previous complications reported for proximal ulnar osteotomies include excessive caudal and varus tilting, luxation of the radial head, synostosis between the radius and ulna, inadvertent radial osteotomy and non-union of the proximal ulna osteotomy.[3] Danielski et al. recently reported that older patients and those with lower bodyweights were at a significantly greater risk of developing complications following a proximal ulna osteotomy with 8.6% of cases forming oligotrophic non-unions. This may be due to excessive motion of the proximal ulnar segment or reduced biologic activity at the osteotomy site. Most of the patients in the study cohort of Danielski et al. were Labrador Retrievers (29.5%), German Shepherds (8.0%), Golden Retrievers (8.0%) or chondrodystrophic breeds (18.2%). While it is plausible that excessive motion of the proximal ulna segment could have led to the development of non-unions, the authors suspected that thermal necrosis and resultant stunting of cellular activity was the primary contributing factor.[14] An additional finding from the abovementioned study was that lighter dogs were more likely to develop complications following a BODPUO. Patients within this study cohort were overrepresented by chondrodystrophic breeds. Angulation of the ulna, which is inherent to chondrodystrophic breeds, could cause application of eccentric mechanical forces to the long axis of the ulna, heightening the risk of developing deformities at the osteotomy site.[14] This was supported by Williams et al., who found that 88% of patients in a multi-institutional study that developed radial head luxation following a proximal ulna osteotomy had angular limb deformities present prior to surgery.[15]

It is noteworthy that neither the angle nor position of the BODPUO in the study by Danielski et al. influenced the complication rate.[14] This finding is supported by Caron et al., where the mean osteotomy trajectories and locations did not differ between patients that developed complications and those that did not. In that study, patients that developed excessive proximal ulna motion had a mean craniocaudal osteotomy angle of 55° and lateral-medial angle of 43°, which was not dissimilar from the target angles of 55 and 48°, respectively.[8] Concern has been expressed within the literature that more proximal ulna osteotomies are associated with excessive motion of the proximal ulna segment. However, measures indicating excessive motion are poorly defined.[3,4,14] A BODPUO is proposed to reduce the morbidity of the procedure by controlling the rotation of the proximal ulna fragment and reducing caudal tipping due to contact between the ulna cortices.[7] Given that the trajectory and location of the osteotomy consistently do not appear to affect the complication rate, further studies are required to assess if a more proximal BODPUO contributes to excessive motion of the osteotomized ulna segment, relative to more distal ulna osteotomies.

To calibrate postoperative radiographs in the present study, the opacity of the 6–8 week follow-up radiographs was adjusted and superimposed onto the immediate postoperative image. The radii from both images were used as a calibration marker to allow simultaneous measurements of proximal ulna tilt from both time points on the same image. This technique was previously used by Bottcher et al. to perfectly superimpose the radii from preoperative and follow-up CT scans and allow for visual assessment of movement of the proximal ulna segment following a dynamic, proximal ulna osteotomy.[1] It is possible that further longitudinal radial growth occurred between the initial and follow-up radiographs, confounding the use of the radius as a calibration marker. However, the majority of patients within this study (88%) were at least 7 months of age, exceeding the reported time frame for radial physeal closure of 7–8 months of age.[16] Measurements of the change in radial length from the immediate and follow-up postoperative radiographs were available for 27 patients. The remaining cases did not have a calibration marker included in their radiographs, preventing accurate measurements of radial length. A mean difference of 0.24 cm in radial length was found between these two time points. The two patients with the largest increases in radial length of 1.1 cm and 1.4 cm were both 5 months of age at the time of surgery. As these increases in radial length were minor, it is likely that this introduced minimal variability when using the radius as a calibration marker to calculate postoperative proximal ulna angles. Most of the follow-up radiographs were taken from 6 to 8 weeks postoperatively, with the earliest being performed 4 weeks after surgery. The radiographic study by Kranz and Lesser found that movement of the proximal ulnar segment following an ulna osteotomy peaked between 2 and 4 weeks postoperatively. Minimal movement was observed after this time point, with changes of only ±1 mm reported. Given that all radiographs were also performed after 4 weeks postoperatively, it is likely that maximal movement of the proximal ulna segment was captured in the radiographs examined.[7]

A preliminary finding from the study was that patient's with IPUA closer to 90° achieved larger changes in proximal ulna angle relative to those with IPUA closer to 60°. This change is likely attributable to a greater upward pull of the triceps when the rotary component of the muscle is perpendicular to the long axis of the ulna. For example, for an ulnar osteotomy performed at 26% of the total ulna length, fitted mean changes in angle for IPUA of 60 and 90° were, respectively, −10° (95% CI: −6 to −14°) and −26° (95% CI: −17 to −35°). This information could be clinically useful in chondrodystrophic breeds when deciding where to perform a BODPUO, due to their higher risk of developing complications including lateral radial head subluxation postoperatively.[14,15]

The correlation between fitted means and observed changes in proximal ulna angle across all 41 elbows was 0.73, indicating that there was good predictive power when solely assessing the effect of the location of the ulna osteotomy. However, assuming that measurement errors were minimal, the scatter within the data set indicates that other determinants must be present that also affect the amount of change in proximal ulna tilt. One of the other possible determinants identified above was the initial angle of the proximal ulna prior to surgery. Additionally, minimal association was found between the craniocaudal angle of the osteotomy on lateral radiographic projections and the change in angle of the proximal ulna postoperatively. No association was found between the length of the ulna osteotomy and the change in angle of the proximal ulna postoperatively. Due to an incomplete data set of craniocaudal radiographic projections, the influence of the lateromedial osteotomy angle on postoperative proximal ulna tilt was unable to be assessed.

Due to the retrospective nature of this study, there were some limitations. The obliquity of the osteotomy and the relative location of the osteotomy were not standardized preoperatively. Standardization of the craniocaudal and lateromedial angles at the recommended 55 and 48°, respectively could have reduced unexplained variability in the final proximal ulna tilt.[4] While 78% of the procedures were performed by a single registered surgical specialist, five surgeons in total were involved in the study. Standardizing the study so that a single surgeon performed all the procedures could have further reduced variability within the data set. It is also possible that the two patients that had single, staged bilateral BODPUO could have had increased weightbearing forces transmitted through the operated limb postoperatively, enhancing caudal tipping of the proximal ulna, confounding the results. Additionally, 60% of complications reported in the study by Caron & Fitzpatrick occurred in patients that had concurrent bilateral BODPUO.[8] In this study cohort, 29.0% of patients had bilateral BODPUO performed in the same procedure. Despite these concerns, to increase the power of the current study, one elbow from each of these dogs was included in statistical analyses. To minimize variability within the data set, preoperative radiographs could have been compared to the 6–8 week follow-up radiographs. The immediate postoperative radiographs were used instead as this allowed for a larger sample size that met the inclusion criteria. Following completion of the ulna osteotomy, tilting of the proximal ulna could have occurred due to immediate kick-back, resulting in an underestimation of the overall change in angle of the proximal ulna. Although the change in proximal ulna angle from before surgery to immediately postoperatively is likely to be minimal, this could account for some of the variation within the data set.

In conclusion, this study demonstrated a strong relationship between the location of a BODPUO and the change in angle of the proximal ulna achieved postoperatively, with more proximal ulnar osteotomies achieving a greater change in proximal ulna tilt. Superimposition of immediate and follow-up postoperative radiographs provide an objective method to quantify the change in proximal ulna angle achieved with surgical intervention. Further studies are required to assess if the magnitude of change in proximal ulna angle affects the long-term clinical outcome, thereby establishing an ideal zone for performing BODPUO.

AUTHOR CONTRIBUTIONS

Farrugia JP, BVSc, DVM, MANZCVS (Small Animal Surgery): Identifying suitable medical records, compiling data, designing the product, formulating a method, interpretation of results and preparation of the manuscript. Snelling SR, FANZCVS (Small Animal Surgery): Formulating the original research idea, guidance and advice throughout design and execution of the research project and for editing and reviewing the manuscript. Morton JM, BVSc (Hons), PhD, MANZCVS (Veterinary Epidemiology): Advising on formulation of the research design, case numbers required, statistically analyzing and interpreting results of the final data set and for reviewing the manuscript. All authors provided a critical review of the manuscript and endorse the final version. All authors are aware of their respective contributions and have confidence in the integrity of all contributions.

CONFLICT OF INTEREST STATEMENT

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

REFERENCES

1. Bottcher P, Brauer S, Werner H. Estimation of joint incongruence in dysplastic canine elbows before and after dynamic proximal ulna osteotomy. *Vet Surg*. 2013;42:371-376. doi:10.1111/j.1532-950X.2012.01085
2. Preston CASK, Taylor KT, Taylor KT, Kass PH, Hagan CE, Stover SM. In vitro experimental study of the effect of radial shortening and ulna ostectomy on contact patterns in the elbow joint of dogs. *Am J Vet Res*. 2001;62:1548-1556.
3. Vezzoni A, Benjamino K. Canine elbow dysplasia: Ununited anconeal process, osteochondritis dissecans, and medial coronoid process disease. *Vet Clin North Am Small Anim Pract*. 2021;51(2):439-474. doi:10.1016/j.cvsm.2020.12.007
4. Fitzpatrick N, Caron A, Solano MA. Bi-oblique dynamic proximal ulna osteotomy in dogs: reconstructed computed tomographic assessment of radioulnar congruence over 12 weeks. *Vet Surg*. 2013;42(6):727-738. doi:10.1111/j.1532-950X.2013.12014.x
5. Krotscheck U, Kalafut S, Meloni G, et al. Effect of ulna ostectomy on intra-articular pressure mapping and contact mechanics of the congruent and incongruent canine elbow ex vivo. *Vet Surg*. 2014;43(3):339-346. doi:10.1111/j.1532-950X.2014.12137.x
6. Rohwedder T, Rebentrost P, Böttcher P. Three-dimensional joint kinematics in a canine elbow joint with medial coronoid disease before and after bi-oblique dynamic proximal ulna osteotomy. *VCOT Open*. 2019;2(2);e44-e49. doi:10.1055/s-0039-1698440
7. Kranz ST, Lesser AS. Radiographic evaluation of osteotomized ulna segments following arthroscopic treatment for canine medial coronoid disease. *Vet Comp Orthop Traumatol*. 2011;24(5):383-388. doi:10.3415/VCOT-10-05-0075 20110805.
8. Caron A, Fitzpatrick N. Bi-oblique dynamic proximal ulna osteotomy: surgical technique and clinical outcome in 86 dogs. *Vet Surg*. 2016;45(3):356-363. doi:10.1111/vsu.12464
9. SR S. Radiographic changes in elbow dysplasia following ulna osteotomy–a case report and review of the literature. *Aust Vet J*. 2004;82:278-281.
10. Zheng B, Agresti A. Summarizing the predictive power of a generalized linear model. *Stat Med*. 2000;19:1771-1781.
11. Haman J, Avery M. ciTools: Confidence or Prediction Intervals, Quantiles, and Probabilities for Statistical Models. R package version 0.6.1. 2020 https://CRAN.R-project.org/package=ciTools
12. R Core Team. R: A Language and Environment for Statistical Computing. 2024 R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/
13. Might KR, Hanzlik KA, Case JB, et al. In vitro comparison of proximal ulnar osteotomy and distal ulnar osteotomy with release of the interosseous ligament in a canine model. *Vet Surg*. 2011;40(3):321-326. doi:10.1111/j.1532-950X.2011.00805.x
14. Danielski A, de Marcos Carpio I, Danielski C, Farrell M, Solano MA. Lower body weight and increasing age are significant risk factors for complications following bi-oblique proximal ulna osteotomy in dogs. *J Am Vet Med Assoc*. 2023;261(11):1-7. doi:10.2460/javma.23.05.0232
15. Williams H, Arthurs G, Burton N, Kulendra E, Radke H, Parsons K. Lateral radial head subluxation as a complication following proximal ulna osteotomy or Ostectomy in eight dogs. *Vet Comp Orthop Traumatol*. 2019;32(3):250-256. doi:10.1055/s-0039-1683389
16. Johnston SA, Tobias KM. *Veterinary Surgery: Small Animal Expert Consult*. Vol 2017. 2nd ed. Elsevier - OHCE; 2017.

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