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Feline radial and ulnar diaphyseal fractures: a retrospective study of 49 cases comparing single bone fixation and dual bone fixation

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Abstract

Objectives The objectives of this study were to report the complications in radial and ulnar diaphyseal fractures in cats and to compare the differences in outcome between single and dual bone internal fixation.

Methods Medical records between 2004 and 2022 were searched retrospectively for cats with antebrachial diaphyseal fractures treated with internal bone-plate fixation. In total, 49 cases were included from six referral hospitals, including one teaching hospital. Patient information was collated, including fracture configuration, location, repair method and clinical outcome as assessed by veterinary physical examination, radiography and owner questionnaire.

Results A total of 47 cats (mean age 4.2 years) were included. Fractures were located distally (24/49, 49%), proximally (13/49, 26.5%) and mid-diaphyseally (12/49, 24.5%). Dual bone fixation was used in 13/49 (26.5%) cases, with only 1/13 (7.7%) having major complications. By comparison, 4/36 (11.1%) of single plated fractures had major complications. Single bone fixation was 14.25 times more likely (95% confidence interval [CI] 2.07–97.99) to have a successful outcome (veterinarian-assigned score of 0) compared with dual bone fixation ($P = 0.007$). When evaluating owner-assessed outcomes, single bone fixation was 9.4 times more likely (95% CI 1.4–61.96) to have a successful outcome (owner score of 0) compared with dual bone fixation ($P = 0.019$).

Conclusions and relevance Fractures that were repaired with single bone fixation had a greater chance of a better outcome. Although the difference was not significant, there was a higher major complication rate and a lower minor complication rate for cases treated with single bone fixation compared with dual bone fixation. The majority of fractures were located in the distal diaphysis. Comminution of the fracture and concurrent orthopaedic issues did not significantly affect the outcome. Further prospective studies with standardised follow-up, radiographic assessment, surgeon and implants are required to truly assess the difference between dual and single bone fixation.

Keywords: Radius; ulna; fracture; dual bone fixation; antebrachium

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Introduction

Radial and ulnar fractures are infrequent in cats, representing 3–8% of all fractures.[1,2] Cats have a highly flexible and extensive interosseous membrane, which allows twice the range of pronation (40–50°) and supination (90–128°) of the antebrachium compared with dogs.[1] It has been suggested that the repair process in radial and ulnar fractures can be more challenging due to a greater chance of movement at the fracture site, which increases the interfragmentary strain and hence the risk of potential complications.[3] In one study, the distribution of weight

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Figure 1 Case 8: mediolateral radiographs of the right forelimb at (a) day 0 and (b) 6 weeks postoperatively showing single bone fixation

in the forelimbs of a cat was 48.2% at a walk, which increased to 148.2% when jumping down from 1 m.[4] This would rapidly increase as height increased.[4] This finding confirms that forelimb stability is of utmost importance for cats, particularly during everyday activities such as jumping and climbing.

The majority of previous studies assessing complications associated with antebrachial fractures have been based on dogs or have a mixed population of predominantly dogs and fewer cats.[5–7] To the authors' knowledge, the largest study of feline antebrachial fractures is that of 28 cats; however, this included multiple methods of repair, including bone plates, external skeletal fixators and external coaptation.[8] Currently, internal fixation is more commonly used to treat feline antebrachial fractures, and its advantages include low morbidity, minimal maintenance and allowing cats to weight bear immediately after surgery.[5] Reported complications related to bone plates include implant failure, bone re-fracture, surgical site infection, non-union, malunion and delayed union.[1,3,9,10] One study suggested that single bone fixation (SBF) in cats (stabilising the radius or ulna alone) may be inadequate due to an insufficient splinting effect on the other bone, and the incidence of major complications was as high as 12.5–31%.[8] Based on previous ex vivo biomechanical studies, dual bone fixation (DBF; plating the radius in conjunction with an intramedullary [IM] pin in the ulna, or plating both the radius and ulna) has been proposed to provide additional stability and significantly reduce the incidence of complications and surgical revision rate.[1,3]

To date, no study has been performed to exclusively compare the complications and clinical outcomes of SBF and DBF in the management of feline antebrachial fractures. The aim of the present study was to report the incidence of complications after internal fixation of antebrachial fractures, and to compare the incidence of postoperative complications and the short- and long-term outcomes of DBF compared with SBF. The authors hypothesise that the use of DBF will have a lower complication rate and improved clinical outcomes compared with SBF.

Materials and methods

The University Veterinary Teaching Hospital Sydney, Veterinary Specialists of Sydney, Southpaws Specialty Surgery for Animals, Veterinary Specialists Aotearoa, Veterinary Specialist Services and Northside Veterinary Specialists databases were searched for cats with antebrachial fractures that occurred between January 2004 and September 2022. The clinical, radiographic and surgical records were reviewed, in addition to telephone interviews with owners. Only cases of cats with radial and/or ulnar diaphyseal fractures that were repaired with SBF (see Figure 1 for an example) or DBF (see Figure 2 for an example) with medical records and radiographs or owner telephone questionnaires were included in this study. Monteggia fractures, physeal fractures and fractures corrected with external skeletal fixators, or no fixation at all, were excluded from the study. The data retrieved from medical records included the following: age; weight; cause of fracture; fracture type; fracture location (proximal, middle or distal third of the bone); and use of graft (cancellous bone graft [CBG] or bone morphogenetic protein [BMP]) and repair method – SBF or DBF. Plate types and lengths were recorded where available. Fracture types were classified as open or closed, and simple or comminuted. Measures of outcome included the following: days to radiographic or clinical union; major and minor complications; and short- (<8 weeks postoperative) and long-term (>8 weeks postoperative) clinical outcomes. Complications were classified into major (when revision surgery was required) and minor (when

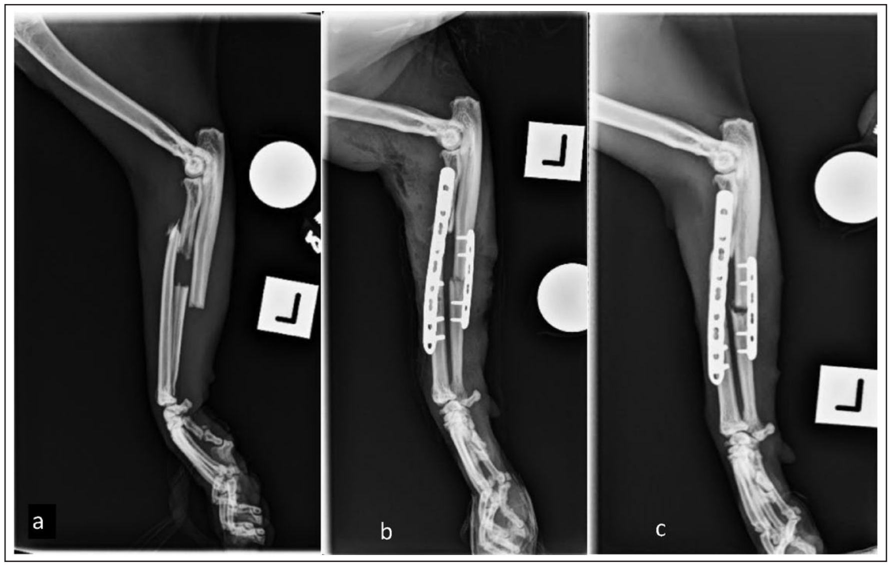

Figure 2 Case 49: mediolateral radiographs of the left forelimb at (a) day 0, (b) immediately postoperatively showing repair with DBF, and (c) 8 weeks postoperatively showing delayed union of the ulna

no surgical treatment was required). Long-term clinical outcomes were assessed by a veterinary surgeon as lame or not lame at follow-up appointments if recorded in the patient file, and by the clients during telephone interviews collected by the first author, which graded outcomes as excellent, good, fair, poor or very poor (see Appendix Table 1 in the supplementary material).[8] At least 3/4 cortices were needed to show bony union to justify radiographic union, and this was determined by the attending veterinarian or by the first author. If the follow-up veterinary records did not include an assessment of lameness or a radiographic evaluation was not available, the case was designated 'lost to follow-up'. A successful outcome was defined as either the veterinarian or the owner reporting no lameness on physical examination or during telephone interview, respectively.

Statistical analysis

Statistical analyses were performed using a commercially available statistical package (Genstat, version 18; VSN International). Before the statistical analysis, outcomes were reduced to binary variables. For veterinarian-assessed and owner-assessed outcomes, respectively, a score of 1 indicated no lameness and 0 indicated some form of lameness; and for postoperative complications, a score of 1 indicated no complications and 0 indicated some form of complication (either minor or major). The data were analysed using logistic regression with an underlying binomial distribution. Outcomes were veterinarian-assessed score, owner-assessed score and presence of complications postoperatively. Factors assessed for an effect on the outcome variables were type of bone fixation (single/dual), other orthopaedic issues (yes/no), fracture configuration (simple/comminuted), use of bone graft (yes/no) and presence of postoperative complications (none/minor/major). *P* values, odds ratios, confidence intervals (CIs) and predicted proportions were calculated. Significance was defined where $P < 0.05$.

Results

Signalment

A total of 47 cats were included in this study, including male castrated (n = 26), male entire (n = 3), female spayed (n = 15) and female entire (n = 3). Two of the cases required revision surgery and were included as separate fractures (cases 27/28 and 34/35). The mean age was 4.2 years (range 5 months to 15.5 years). The mean weight was 4.4 kg (range 2.6–7.15 kg). Breeds included the following: domestic shorthair (n = 25); Birman (n = 4), domestic mediumhair (n = 3); Bengal, British Shorthair, Siamese cross (n = 2 each); and the remainder were Ragdoll, Ragdoll cross, Scottish Fold, Russian Blue, Korat, Burmilla, Tonkinese, Ocicat and Burmese (n = 1 each).

Fracture location Of all 49 fractures, 27 were confined to the left limb, 20 to the right and two were not specified. Nine of the fractures were of the radius only; there was one ulnar fracture with an intact radius and 39 combined radial/ulnar fractures, of which 26 were repaired with SBF and 13 with DBF. The cause of the fractures included the following: unknown (n = 21); falls from a height (n = 15); fight related (n = 3); caught in a trap (n = 3); hit by a car (HBC) (n = 2); inadvertent trauma by the owner (n = 2); and failed previous repair (n = 3).

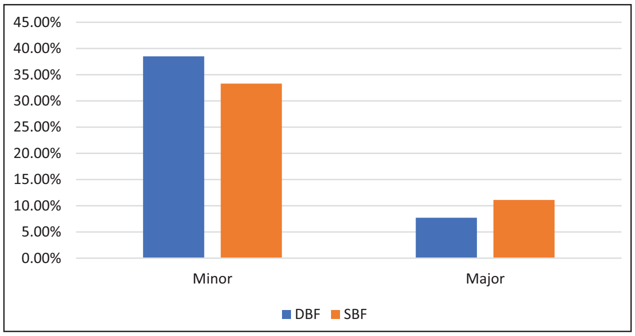

Figure 3 Minor and major complication rates of dual bone fixation (DBF) vs single bone fixation (SBF)

Of the 49 diaphyseal antebrachial fractures, 24 (49%) were distal, 13 (26.5%) were proximal and 12 (24.5%) were mid-diaphyseal. Of these cases, 13 were repaired with DBF, 35 with SBF of the radius and one with SBF of the ulna. Of the 49 fractures, five were open fractures, all of which were located on the left limb.

Complications

Of the 49 cases, 17 (34.7%) had minor complications. Of the 13 DBF cases, five (38.5%) had minor complications, compared with 12/36 (33.3%) in the SBF group. Of the 49 fractures, five (10.2%) had major complications. Major complications were found in 1/13 (7.7%) DBF cases and 4/36 (11.1%) SBF cases. Of these five fractures, two (40%) were located in the proximal third of the radius and ulna, two (40%) were located in the distal third and one (20%) was located in the middle third of the ulna. Case 6 (see Appendix Table 2 in the supplementary material, Tables 1 and 2), an open fracture in the proximal third of the antebrachium, required amputation given poor limb viability in the postoperative period. Case 18 (see Appendix Table 2 in the supplementary material, Table 1) was advised to have implants removed due to discomfort associated with the plate on palpation and lameness. There was delayed union of the radius and the ulna at 14 weeks postoperatively; although further surgery was recommended, this case was lost to follow-up. Case 27 (see Appendix Table 2 in the supplementary material, Table 1) sustained an open fracture of the distal radius and ulna, which initially had the fracture repaired at a referring veterinarian, and radiographs taken 6 weeks postoperatively showed delayed union of the fracture site. This repair failed 9 months later, requiring revision. At the initial time of injury (HBC), the right hind paw was severed, and the tibia sustained complex trauma, resulting in the cat subsequently undergoing a hindlimb amputation. Case 34 (see Appendix Table 2 in the supplementary material, Table 1) had a major complication after an initial fracture repair after a cat fight, which resulted in a long oblique fracture of the proximal radius with the ulna intact. A total of 18 months after this surgery, the bone fractured just distal to the initial implant. The cat was walking well before the second fracture. The owner reported ongoing lameness after the second surgery. Case 38 (see Appendix Table 2 in the supplementary material, Table 1) required surgical debridement of the wound due to partial dehiscence and plate exposure 2 weeks after the original surgery of a grade 1 open mid-diaphyseal comminuted fracture of the ulna. This fracture showed delayed healing on the 8-week radiographs and there was screw loosening, necessitating removal of the implants at 12 weeks.

The presence of postoperative complications was not significantly affected by bone fixation, presence of other orthopaedic issues or fracture type ($P = 0.952$, 0.743 and 0.422, respectively) (Table 3).

Comminution

There were 21 fractures with comminution identified. Of the 21 fractures, two (9.5%) had major complications requiring surgical intervention (one amputation and one surgical wound debridement). One case (case 46; see Appendix Table 2 in the supplementary material, Table 1) had delayed union at 20 weeks but was lost to follow-up. This compares with 3/28 (10.7%) of the non-comminuted fractures sustaining major complications. Comminution had no significant effect on the final outcome (Table 3).

Orthopaedic issues

Of the 49 cases, nine had other concurrent orthopaedic issues. These included major degloving injury to the fractured limb, puncture wounds to other limbs, fracture of the metacarpal bones of the same limb, fracture of the distal metaphysis of the femur, severe arthritis, severed right hindlimb paw and trauma after an HBC accident requiring mid-femoral amputation, tarsal subluxation with chip fracture and a scapular fracture on the same limb as the antebrachial fracture. In total, 2/9 (22.2%) of these cases had major complications in relation to their antebrachial repair. This compares with 3/40 (7.5%) fractures with no concurrent orthopaedic issues requiring further intervention. Although there was a large variation between the two groups, no significant difference was identified in these results (Table 3).

Fixation methods

DBF was used in 13/49 (26.5%) cases, with only 1/13 (7.7%) having major complications (Table 2). This compares with 4/36 (11.1%) of SBFs with major complications (Figure 3). With successful veterinary assessment outcomes, SBF was 14.25 times more likely (95% CI 2.07–97.99) to have a successful outcome (veterinary score of 0) compared with DBF ($P = 0.007$) (Table 3). With owner-assessed outcomes, SBF was 9.4 times more likely (95% CI 1.4–61.96) to have a successful outcome (owner score of 0) compared with DBF ($P = 0.019$) (Table 3). Of the 13 DBF cases, 9 (69.2%) cases had comminution, compared with 13/36 (36.1%) of the SBF cases.

Table 1 Cases with minor and/or major complications, including configuration, details of complications and final outcomes

Case	Weight (kg)	Age	Signalment	Cause	Fracture configuration	SBF/ DBF	Implant description	Graft	Other orthopaedic issues	Time to union	Postoperative complication	Final outcome (veterinarian lameness score)	Owner response (1–5)
3	4.3	5y 11m	MN Bengal	UK	Left: comminuted, mid R/U	DBF	R: 2.0, LCP U: 1.5, LCP	Cancellous bone graft	None	U: 13 weeks R: delayed union	Minor: delayed union	0	2
6	4.5	6y 7m	FS DSH	Caught in a trap	Left: open, comminuted, proximal R/U	DBF	R: 2.0, 8-hole LC-DCP U: 1.5, 8-hole DCP	BMP	Concurrent damage to soft tissues of fractured limb with compromise of blood supply	N/A	Major: no perfusion to the limb after 3 days. Limb was amputated	0	5
8	3.6	9m	MN DSH	UK	Right: comminuted, mid R	SBF	R: 1.5, UK plate	None	None	UK (fracture still present at 6 weeks)	Minor: interdigital dermatitis and decubital ulcer of the ipsilateral elbow	1	2
12	5.7	1y 9m	MN DSH	Fall	Left: comminuted distal R/U	SBF	R: 2.0, 9-hole LCP	None	Transverse fracture of the distal diaphysis of the third and fourth metacarpus with moderate craniolateral displacement	6 weeks	Minor: slight knuckling, weight loss, muscle atrophy of surgical limb	1	LTFU
13	7.15	1y 3m	MN Bengal	UK	Right: comminuted mid R/U	SBF	R: 2.0, 6-hole LCP	None	None	8 weeks clinical union	Minor: digital swelling postoperatively of surgical limb	1	1
18	3.6	4y 2m	MN Ragdoll	Non-union of previous external fixator	Right: transverse, distal R/U	SBF	R: 2.0, 12-hole plate	CBG	Translation of the distal radial segment and fracture at the proximal end of the external fixator	14 weeks (radius only)	Minor: carpal laxity at 1 week but resolved on its own. Soft tissue infection Major: delayed union, implant removal required	1	LTFU

(Continued)

Table 1 (Continued)

Case	Weight (kg)	Age	Signalment	Cause	Fracture configuration	SBF/ DBF	Implant description	Graft	Other orthopaedic issues	Time to union	Postoperative complication	Final outcome (veterinarian lameness score)	Owner response (1–5)
19	5	9 y	MN DSH	UK	Left: transverse distal R/U	SBF	R: 2.0, 8-hole LCP	None	None	UK	None	1	1
20	3.2	3 y	FS Birman	UK	Right: UK, distal R/U	SBF	R: 2.0, 6-hole UK plate	None	None	UK	Minor: 3/5 lameness at 3 weeks postoperatively	LTFU	1
21	5.1	14 y	MN Birman	Dog attack	Left: open, short oblique, proximal R/U	DBF	R: 2.0, 9-hole DCP U: 2.0, 6-hole DCP	None	None	9 weeks (radius only)	Minor: delayed union of the ulnar fracture, elbow incongruency	0	1
22	5.4	7 m	MN DSH	Caught in door	Right: comminuted distal, R/U	SBF	R: 2.0, 7-hole UK plate	None	None	12 weeks	Minor: distal screw backing out; however, bone healed at this point. No further surgery required	1	1
23	6	3 y 7 m	MN DMH	Fall	Left: short oblique, distal R/U	SBF	R: 2.0, 8-hole UK plate	CBG	None	10 weeks (radius only)	Minor: delayed union of ulna at time of final radiograph	0	LTFU
26	5.2	4 y 1 m	ME Korat	UK	Right: short oblique, distal R/U	SBF	R: 20 G cerclage wire, 2.4, 8-hole cuttable plate	None	None	10 weeks	Minor: seroma formation and mild dehiscence. Managed with bandage. Decubital ulcers from bandages	1	1
27	3.3	11 m	FS DSH	HBC	Left: open, transverse, distal R/U	SBF	R: 2.0, 7-hole cuttable plate	None	Severed right hind paw and fracture of the tibia (amputated mid-femur)	6-week radiographs: delayed union	Minor: infection of wound Major: implant loosening after 9 months	0	LTFU
28	3.5	1 y 8 m	FS DSH	Previous repair failure	Left: transverse, distal R/U	SBF	R: 2.0, 12-hole DCP	CBG on second surgery	Severed right hind paw	8 weeks (radius only)	Minor: delayed union of ulna	1	1

(Continued)

Table 1 (Continued)

Case	Weight (kg)	Age	Signalment	Cause	Fracture configuration	SBF/ DBF	Implant description	Graft	Other orthopaedic issues	Time to union	Postoperative complication	Final outcome (veterinarian lameness score)	Owner response (1–5)
34	UK	2y 11m	FS Tonkinese	Cat fight	Left: oblique, proximal R	SBF	R: 2.0, LCP, single positional 2.4 mm screw	None	None	6 weeks	Major: implant failure after 18 months	1	LTFU
38	7	UK	MN DSH	Dog attack	Left: comminuted, mid U	SBF	U: 1.5, 10-hole LC-DCP	None	None	8 weeks	Major: wound breakdown requiring surgical debridement	LTFU	LTFU
40	5.8	1y 7m	MN DSH	UK	Left: transverse, distal R/U	SBF	R: 2.0, 9-hole LCP	None	None	UK	Minor: distal limb oedema, resolved with compressive bandage	LTFU	1
42	4.1	2y	MN DSH	UK	Right: comminuted, proximal R/U	SBF	R: 2.0, 10-hole LCP U: 2.5 mm K-wire	None	None	5 weeks	Minor: soft tissue infection	0	LTFU
46	5	11y	MN Siamese cross	Fall	Left: comminuted, proximal R/U	SBF	R: 2.0, 12-hole LCP	None	None	UK: 20 weeks delayed union	Minor: delayed union	1	LTFU
48	4	3y	MN DSH	UK	Left: comminuted short oblique, proximal R/U	DBF	R: 2.0, locking plate U: 2.0, locking plate	None	None	UK	Minor: decubital ulcer at digit 1 nail bed, 4/5 lame at 1-week recheck	LTFU	LTFU
49	4	13y	FS DSH	UK	Left: comminuted, proximal R/U	DBF	R: 2.0, 10-hole locking plate U: 1.5, 6-hole locking plate	None	None	8 weeks delayed union	Minor: delayed union	1	1

BMP = bone morphogenetic protein; CBG = cancellous bone graft; DBF = dual bone fixation; DCP = dynamic compression plate; DMH = domestic mediumhair; DSH = domestic shorthair; FS = female spayed; HBC = hit by car; LC-DCP = limited contact dynamic compression plate; LCP = locking compression plate; LTFU = lost to follow-up; m = months; ME = male entire; MN = male neutered; R = radius; SBF = single bone fixation; U = ulna; UK = unknown; y = years

Table 2 Cases with dual bone fixation, including configuration, details of complications and final outcomes

Case	Weight (kg)	Age	Signalment	Cause	Fracture configuration	SBF/DBF	Implant description	Graft	Other orthopaedic issues	Time to union	Postoperative complication	Final outcome (veterinarian lameness score)	Owner response (1–5)
1	5.7	15 y 8 m	MN DSH	UK	Right: distal R/U short oblique fracture	DBF	R: 2.0, locking T-plate U: 1.5, LCP	None	None	N/A	None	0	2
3	4.3	5 y 11 m	MN Bengal	UK	Left: comminuted, mid R/U	DBF	R: 2.0, LCP U: 1.5, LCP	CBG	None	U: 13 weeks R: delayed union	Minor: delayed union	0	2
5	5.2	2 y 5 m	MN Ragdoll cross	UK	Right: comminuted, mid R/U	DBF	R: 2.0, LCP U: 1.5, LCP	None	None	UK	None	UK	1
6	4.5	6 y 7 m	FS DSH	Caught in a trap	Left: open, comminuted, proximal R/U	DBF	R: 2.0, 8-hole LC-DCP U: 1.5, 8-hole DCP	BMP	Concurrent damage to soft tissues of fractured limb with compromise of blood supply	N/A	Major: no perfusion to the limb after 3 days. Limb was amputated	0	5
7	3.9	2 y 11 m	FS DMH	Fall	Right: comminuted, proximal R/U	DBF	R: 2.0, LCP U: 1.5, LCP	None	None	UK	None	0	2
16	2.6	6 m	ME BSH	Fall	Right: comminuted, distal R/U	DBF	R: 1.5/2.0, cuttable plate U: 1.5/2.0, cuttable plate	None	None	4 weeks no union	None	LTFU	LTFU
21	5.1	14 y	MN Birman	Dog attack	Left: open, short oblique, proximal R/U	DBF	R: 2.0, 9-hole DCP U: 2.0, 6-hole DCP	None	None	9 weeks (radius only)	Minor: delayed union of the ulnar fracture, elbow incongruency	0	1
31	5	2 y 11 m	MN DSH	UK	Right: UK, mid R/U	DBF	R: 2.4, 8-hole locking plate U: 2.0, 6-hole locking plate	None	None	6 weeks	None	1	LTFU

(Continued)

Table 2 (Continued)

Case	Weight (kg)	Age	Signalment	Cause	Fracture configuration	SBF/ DBF	Implant description	Graft	Other orthopaedic issues	Time to union	Postoperative complication	Final outcome (veterinarian lameness score)	Owner response (1–5)
32	4	7 y 11 m	MN DSH	UK	Left: UK, distal R/U	DBF	R: 2.4, 6-hole DCP U: 2.0, 5-hole cuttable bone plate	None	None	6 weeks	None	1	LTFU
36	4	1 y 2 m	FS Ocicat	UK	Left: comminuted, mid R/U	DBF	R: 2.0, 10-hole LCP U: 2.0, 8-hole LCP	None	None	6 weeks	None	1	2
42	4.1	2 y	MN DSH	UK	Right: comminuted, proximal R/U	DBF	R: 2.0, 10-hole LCP U: 2.5 mm K-wire	None	None	5 weeks	Minor: soft tissue infection	0	LTFU
48	4	3 y	MN DSH	UK	Left: comminuted short oblique, proximal R/U	DBF	R: 2.0 locking plate U: 2.0 locking plate	None	None	UK	Minor: decubital ulcer at digit 1 nail bed, 4/5 lame at 1-week recheck	LTFU	LTFU
49	4	13 y	FS DSH	UK	Left: comminuted, proximal R/U	DBF	R: 2.0, 10-hole locking plate U: 1.5, 6-hole locking plate	None	None	8 weeks delayed union	Minor: delayed union	1	1

BMP = bone morphogenetic protein; BSH = British Shorthair; CBG = cancellous bone graft; DBF = dual bone fixation; DCP = dynamic compression plate; DMH = domestic mediumhair; DSH = domestic shorthair; FS = female spayed; LC-DCP = limited contact dynamic compression plate; LCP = locking compression plate; LTFU = lost to follow-up; m = months; ME = male entire; MN = male neutered; R = radius; SBF = single bone fixation; U = ulna; UK = unknown; y = years

Table 3 Statistical analysis of the effects of type of fracture and bone fixation, other orthopaedic issues and postoperative complications on outcomes

Outcome	Variable	Category	OR	95% CI	*P* value	Predicted proportion	Standard error
Veterinarian-assessed outcome	Bone fixation	DBF	–			0.4	0.154
		SBF	14.25	2.07–97.99	0.007	0.9	0.064
	Other orthopaedic issues	No	–			0.704	0.088
		Yes	0.4211	0.09–1.865	0.255	0.5	0.158
	Fracture type	Comminuted	–			0.563	0.124
		Simple	1.426	0.35–5.775	0.619	0.647	0.116
	Bone graft	No	–			0.677	0.084
		Yes	0.476	0.081–2.789	0.411	0.5	0.204
	Postoperative complication	Major	–			0.4	0.219
		Minor	2.625	0.3–22.93		0.636	0.144
		None	3.75	0.49–28.3	0.438	0.714	0.098
Owner-assessed outcome	Bone fixation	DBF	–			0.375	0.17
		SBF	9.4	1.4–61.96	0.019	0.85	0.08
	Other orthopaedic issues	No	–			0.71	0.09
		Yes	1.235	0.109–13.95	0.864	0.75	0.21
	Fracture type	Comminuted	–			0.583	0.142
		Simple	2.381	0.424–13.36	0.324	0.769	0.117
	Bone graft	No	–			0.79	0.08
		Yes	0.087	0.007–1.029	0.053	0.25	0.215
	Postoperative complication	Major	–			0.0005	0.013
		Minor	4.2	0.365–84.5		0.8	0.126
		None	8.6	0.86–112.6	0.733	0.6667	0.122
Postoperative complication	Bone fixation	DBF	–			0.462	0.138
		SBF	1.26	0.262–3.526	0.952	0.452	0.09
	Other orthopaedic issues	No	–			0.441	0.085
		Yes	1.649	0.309–5.2	0.743	0.5	0.16
	Fracture type	Complicated	–			0.55	0.11
		Simple	0.747	0.168–2.1	0.422	0.42	0.11

Reference levels for ORs were DBF, no other orthopaedic issues, complicated fracture type, no bone graft and major postoperative complication
CI = confidence interval; DBF = dual bone fixation; OR = odds ratio; SBF = single bone fixation

Bone grafts CBGs were used in five fractures, and BMP was used in one. Of the cases with CBG, one (20%) had major complications requiring the plate to be removed; this case was lost to follow-up (case 18). The one case in which BMP was used resulted in amputation of the fractured limb (case 6) within the first week.

Follow-up

A total of 31 cases had follow-up radiographs. Of these, 22 (71%) had healing of the fracture of the radius at a mean of 8.8 weeks (range 5–14 weeks). Seven cases were considered to have delayed union at the time of final radiographs; however, there were no further follow-up radiographs to confirm healing at a later date.

Of the 49 cases, 28 were available for long-term follow-up (6 months or more) with owner questionnaires: 20/28 were excellent; 6/28 were good; 1/28 was fair; and 1/28 was poor. The one case that was poor required amputation (case 6).

Discussion

There was no significant difference in the rate of minor and major complications between the SBF and DBF groups (Table 3). Veterinarian-assessed scores and owner-assessed outcomes were better for SBF than DBF (Table 3). Based on veterinarian-assessed scores, SBF was 14.25 times more likely (95% CI 2.07–97.99) to have a successful outcome with no lameness compared with DBF ($P = 0.007$) (Table 3). Based on the owner questionnaire, SBF was 9.4 times more likely (95% CI 1.4–61.96) to have a successful outcome with no lameness compared with DBF ($P = 0.019$) (Table 3). The hypothesis that DBF would have a lower complication rate and better outcomes was therefore rejected.

Radius and ulna fractures in cats comprise 5–13.8% of all long-bone fractures.[2,9,11,12] To the authors' knowledge, there are no large cohort studies that document the delayed union rates in cats, so comparisons to dogs are not directly possible. The rate of non-union in the radius and ulna in cats is 16.7%, compared with dogs, in which 17.9% of radius and ulna fractures result in delayed union and there is a non-union rate of 3.4%.[11,13] This may be due to the increased motion in the forelimb of cats compared with dogs, with cats having almost double the range of supination.[1,9,11] The range of feline antebrachial rotation is most similar to that of humans.[14] In human surgery, it is commonplace to plate both the radius and ulna separately in antebrachial fractures due to concerns of increased strain on the fracture site increasing the risk of complications.[5,7] In this study, there were seven (14.3%) cases of delayed union, which is within the reported range of previous studies; however, this may be higher due to the fact that only 63% of the cases in the present study had follow-up radiographs after the fracture repair.[11,12]

Previous biomechanical studies have shown the potential benefits of DBF in cats.[1,3] The authors demonstrated that there was an increase in stiffness where DBF was used compared with single plating of the radius alone. Plating of the radius with the use of an IM pin in the ulna increased stiffness.[1,3] In the present study, 1/13 (7.7%) of the DBF cats had major complications; however, this was due to poor vascular viability of the limb at the time of the surgery. This compares with 4/36 (11.1%) cats treated with SBF that required revision surgery. Despite this variation in percentage, the final outcome scores of the veterinarian and owner assessments were significantly better for cases with SBF. This may be due to reduced disruption of the blood supply when plating just one bone, low case numbers or that the fractures themselves were inherently less biologically compromised.[8] There may also be a clinical decision bias where DBF may be used in more complex fractures that are less stable and require stiffer constructs as determined by the surgeon. It is important to note that 13/36 (36%) of the SBF cases had either an intact radius or ulna, which would act as an internal splint and potentially aid in the healing of the fracture and making it more likely for them to have a good outcome compared with DBF.

An added benefit of DBF in humans may be the reduction of synostosis formation between the radius and ulna, which subsequently reduces the full range of motion and is a significant complication in humans.[15] The rate of synostosis after the repair of antebrachial fractures in small animals is largely unknown since the radiographic evidence may not be present, but there may be a significant fibrous union between the two bones. Once a synostosis has formed, in humans the complication and recurrence rates are quite high; therefore, avoiding the occurrence of this complication is important.[16–18] The consequence of synostosis in cats may be reduced limb function because supination is vital for climbing, grooming, catching prey and hunting.[9,19] In the present study, no synostosis was noted in any follow-up radiographs.

Of the fractures, 49% were distal, 26.5% were proximal and 24.5% were mid-diaphyseal. This differs from a previous study where the majority of fractures were located in the mid-diaphysis (57.2%), with the proximal and distal diaphysis comprising 25% and 17.8%, respectively.[8] However, our study is similar to others that show a higher percentage of fractures in the distal diaphysis in cats and small dog breeds.[2,20–22] It is important to note that the prevalence of antebrachial fractures in cats is much lower than in dogs: 2–8% and 18%, respectively.[2,23] This has previously been hypothesised to be due to higher cortical bone density, thicker trabeculae and increased anisotropy in cats compared with dogs.[23] The discrepancy in fracture location between studies may be due to the low numbers of feline antebrachial fractures previously described.[8]

The current literature shows that comminution and high-grade open fractures increase the risk of failure to heal, which is seen in tibial and femoral fractures in cats and in humans.[24–27] This is contrary to the results of the present study, where the incidence of major complications in cases requiring revision surgery or even limb amputation was 10.2% and comminution was noted in only two cases (9.5% of all cases with comminution); however, of the remaining cases, three (10.7%) with major complications had no comminution. This was not found to be statistically significant (Table 3). This discrepancy may be due to the sample size included, or the number of cats lost to follow-up in this study. Concurrent orthopaedic issues had an increased percentage of major complications (22.2%) compared with the other cases in the study (7.5%). This is in line with previous reports; however, this was not significant in the present study (Table 3).[8]

The mean time to union of cases that had returned for repeat radiography was 8.8 weeks (range 5–14 weeks). This compares favourably with a previous study where the mean time to radiographic union was 12.9 weeks.[8] There was a large proportion of cases that did not return for follow-up radiographs after the original procedure or after initial radiographs. Of 31 cases, 22 (71%) had shown adequate healing of the radius; 5/22 (22.7%) of these cases had delayed union of the ulna. The low number of postoperative radiographs may be due to the clients being satisfied with limb function after surgery and not returning for follow-up. This is supported by the results of the telephone interviews, with 92.9% of the cases reported as excellent or good, with only one cat classified as poor and one cat as fair.

The authors acknowledge that there are limitations to this study with it being retrospective, involving six referral veterinary hospitals, with cases lost to follow-up, multiple surgeons, various implants and variable after-care instructions. Having a non-standardised method of assessing lameness scores in the different hospitals can be corrected by using force-plate analysis at set time points in the recovery period. To truly understand the difference in clinical significance between single and dual bone plating, a prospective randomised controlled study would need to be performed. However, given the rarity of cats presenting with antebrachial fractures, it would be difficult to achieve a sample size of reasonable significance. Due to the small number of responses other than 0 for the veterinary assessment score, responses were reduced to a binary outcome (the animal was scored as either lame or not lame), which could have skewed the results as there were fewer responses for DBF. This meant that cases that were mildly lame were grouped with cases that were markedly lame and classed as unsuccessful. This could be addressed if there were a larger cohort size in this study. However, this was not achievable with the small dataset, which meant that assessing outcomes as anything more complex than binary reduced statistical power.

Conclusions

Feline antebrachial fractures that were managed with SBF had a greater chance of a better outcome as assessed by veterinarians and owners compared with those managed with DBF. The location of fractures in this study is similar to that in other reports, with the majority located in the distal diaphysis, similar to that seen in small and toy-breed dogs. Comminution and concurrent orthopaedic issues did not significantly affect the outcome of cats in this study. Further prospective studies with consistent follow-up, radiographic assessment, surgeon and implants are required to truly assess the difference between DBF and SBF. Although the difference was not significant, cases treated with DBF had a lower incidence of major complications, and a higher rate of minor complications.

Supplementary material The following files are available as supplementary material:
Appendix Table 1: Owner response scores and their description.
Appendix Table 2: All cases of feline antebrachial fractures, includes configuration, complications, and final outcomes.

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Ethical approval The work described in this manuscript involved the use of non-experimental (owned or unowned) animals. Established internationally recognised high standards ('best practice') of veterinary clinical care for the individual patient were always followed and/or this work involved the use of cadavers. Ethical approval from a committee was therefore not specifically required for publication in *JFMS*. Although not required, where ethical approval was still obtained, it is stated in the manuscript.

Informed consent Informed consent (verbal or written) was obtained from the owner or legal custodian of all animal(s) described in this work (experimental or non-experimental animals, including cadavers) for all procedure(s) undertaken (prospective or retrospective studies). No animals or people are identifiable within this publication, and therefore additional informed consent for publication was not required.

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