Initial Clinical Application and Results of the Advanced Locking Plate System (ALPS) in Small Animal Orthopedics: Two Hundred Eighty Two Procedures

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ABSTRACT

Dogs and cats with fractures, arthrodeses, or corrective osteotomies (282 fixations) stabilized using the ALPS bone plating system between May 2007 and April 2012 were evaluated retrospectively to describe the authors' experience with this system, assess rate of bone union, and evaluate post-operative complications. Cases with follow-up radiographs taken at least 8 weeks postoperatively or cases with bone healing confirmed prior to week 8 were included. Signalment, preoperative infection, fracture location, fracture type, surgical fixation method, implant size, additional fixation, intraoperative complications, and postoperative complications were recorded for each patient.

Two hundred eighty-two fixations were performed on 266 patients, including 240 fractures, 26 corrective osteotomies, 14 arthrodesis, and 2 additional procedures. All 10 reported intraoperative complications occurred in the first year; each involved screw failure. Postoperative complications were reported in 9 of the 282 procedures (3.2%), of which 7 cases were major complications (2.5%) and 2 cases were minor complications (0.7%). With the exception of two amputations, all treated cases achieved bone union or progression towards bone union (99.3%). This study demonstrated a high rate of bone union (99.3%), accompanied by a low postoperative complication rate (3.2%), when using the ALPS system in

small animal orthopedics.

INTRODUCTION

The principles of internal fracture fixation by plating are based on the conviction that precise reconstruction and absolute stability are essential for successful bone union (Mueller, et al, 1970; Schatzker, et al, 1987; and Perren, 2002). However, this fixation type typically requires an extensive surgical approach, often resulting in damage to local soft tissue and blood supply, which may lead to infection and possibly delayed healing or non-union, as opposed to an open but do not touch approach (Perren, 2002). Conventional bone plate fixation has also been associated with early temporary increased bone porosity under the bone plate, resulting from insult to the periosteal blood supply secondary to implant-bone contact (Perren, 2002). Biological internal fixation is a recently developed alternative providing optimal, rather than absolute, stability with minimal soft tissue disturbance and minimal underlying bone contact (Perren, 2002; Hernanz, et al, 2007).

A new generation of plates, called internal fixators, has been developed utilizing a locking mechanism between the plate hole and the screw head (Perren, 2002; Voss, et al., 2009). These devices are widely used in human surgery and have demonstrated advantages, including decreased risk of screw loosening, allowance for insertion of only monocortical screws, fewer screws needed for stability, and avoidance of bone necrosis under the plate (Perren, 2002; Perren, 2003; Miller, et al, 2007).

The Advanced Locking Plate System (ALPS) (Kyon, Zurich Switzerland), was conceptualized and designed to preserve the vascular supply, increase resistance to infection, and accelerate healing (Tepic, presented 2007). Titanium ALPS plates have holes designed for either non-locking or locking screws (titanium alloy). The ALPS system integrates the Point Contact Fixator (PC-Fix) development work from the AO Research Institute, Davos, Switzerland (Tepic, et al, 1997; Haas, et al, 2001; Perren, 2002). Since 2007, ALPS has been used for fracture stabilization, arthrodeses, and osteotomies in small animals. To the authors' knowledge, there is only one published report on ALPS use, and experience with its application is limited (Inauen, et al, 2009).

This retrospective study describes our experience with ALPS, the rate of bone union, our postoperative complications, as well as the type and frequency of our associated complications. Fractures of the radius and ulna are particularly common in small dogs, and often result in higher complication rates. Therefore, our comparatively low small dog radioulnar fracture complication rate is particularly interesting.

MATERIALS AND METHODS

Inclusion Criteria

Medical records from dogs and cats with fractures, arthrodeses, or corrective osteotomies stabilized using ALPS between May 2007 and April 2012 were included in this retrospective study. Patients with radiographically confirmed bone healing prior to 8 weeks, and those with radiographs out to at least 8 weeks postoperative, were included.

Fracture Classification

Fractures were classified as diaphyseal, metaphyseal, or articular and fracture type was classified as simple:

- transverse or short oblique
- simple long oblique or spiral, comminuted-1 (maximum two large cortical fragments)
- comminuted-1' (segmental fracture), and
- comminuted-2 (more than two cortical fragments), or delayed union/non-union

Medical records for patients undergoing arthrodeses or corrective osteotomies were classified by location.

Implants

Type of procedure, plate size, and any additional fixation were retrieved from medical records. Four ALPS plate sizes, identified by plate width, were used in this study (5, 6.5, 8, and 10 mm). Whenever indicated, locking screws were used (1.5 mm cortical/2.4 mm locking for 5mm and 6.5 mm plate; 2.4 mm cortical/3.2 mm locking for 8 mm plate; 2.7 mm cortical/4.0 mm locking for 10 mm plate). In some cases, the shortest locking screw was too long and the far cortex was engaged, or standard non-locking screws were used. Plate sizes were selected using the suggested implant reference chart (Figure 1). Double or triple plating (Table 1) was also implemented.In cases of insufficient bone support to provide additional support for total load across the fracture, or to increase strength when a distal fracture fragment would allow only one, or possibly two, screws in a single plate.

Surgical Technique

Standard surgical approaches were made. Care was taken to not further disrupt periosteal or muscular attachments to bone or bone fragments, and to not disturb fracture hematomas. Axial and rotational alignments were re-established by manual traction and manipulation. The majority of fracture repairs used an "open but do not touch" technique, as described by Houlton, et al. (2005), a variation of open reduction permitting viewing of fracture fragments with minimal biological consequences.

Bacterial Culture

Bacterial cultures with strain identification were performed on all dogs with open fractures and those that failed to heal following surgery in another hospital. Treatment was based on susceptibility results.

Postoperative Care

The postoperative care protocol included 2 to 3 days of antibiotic therapy and NSAID administration, the intermittent application of an icepack for swelling and cage rest pending radiographic confirmation of bone union. Dogs were allowed leash walking beginning 2 weeks postoperatively for 5 to 10 minutes, two or three times a day. This was increased to 10 to 15 minutes at 4 weeks postoperative.

Evaluation of Outcome

Clinical assessment for lameness, complication evaluation, and radiographs were generally performed every 3 weeks for all patients, whether at the referral facility or by the referring veterinarian. Records of included animals were followed to approximately 8 weeks or until bone healing was noted radiographically. The referral hospital confirmed fracture union with the presence of a bridging callus over three cortices on two orthogonal projections. Fracture union was determined in all cases by the radiographic appearance of a visible callus bridging at least one cortex on both orthogonal views (Hernanz, et al. (2007)). Cases with radiographic signs showing good healing progression, no signs of implant loosening, and no indication of other abnormalities at follow-up, were assumed to be free of complications. Postoperative complications were noted and classified as either major, requiring surgery or amputation, or minor, not requiring surgical intervention.

RESULTS

Patient and Fracture Description

Two hundred eighty-two procedures were performed on 266 patients (Table 1, 2, and 3), including 240 fractures, 26 corrective osteotomies, 14 arthrodeses, 1 preventive fixation following a tibial turberosity advancement, and 1 triple pelvic osteotomy revision. Patients had a mean age and weight of 32 months and 4.6 kg respectively. Surgeries were performed by either a diplomate of the Japanese College of Veterinary Surgeons (JCVS) or a JCVS resident.

Of the 155 patients with radioulnar fractures, 140 patients (91%) were small breed dogs, including Toy poodles, Pomeranians, Chihuahuas, and Italian Greyhounds. There were 211 long-bone fractures. Prior to ALPS fixation, eight fractures were considered to have a delayed union, and 21 were nonunion.

Bacterial cultures with strain identification, using specimens collected at surgery, were performed on 15 dogs and 3 cats with open fractures and 38 dogs and 5 cats that had prior surgery in other hospitals, but

Table 1. *Individual Case Signalment, Fracture Type and Fixation*

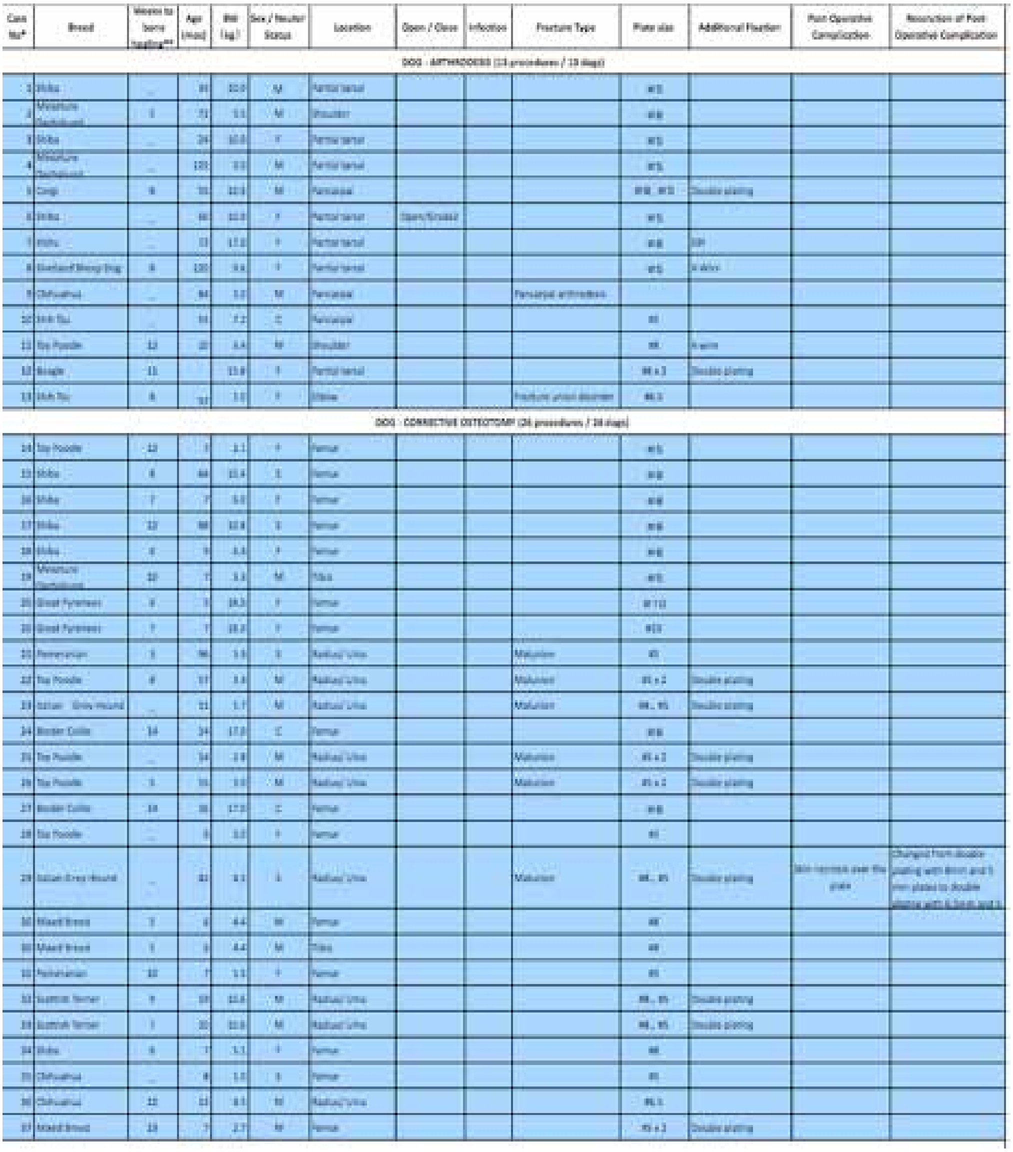
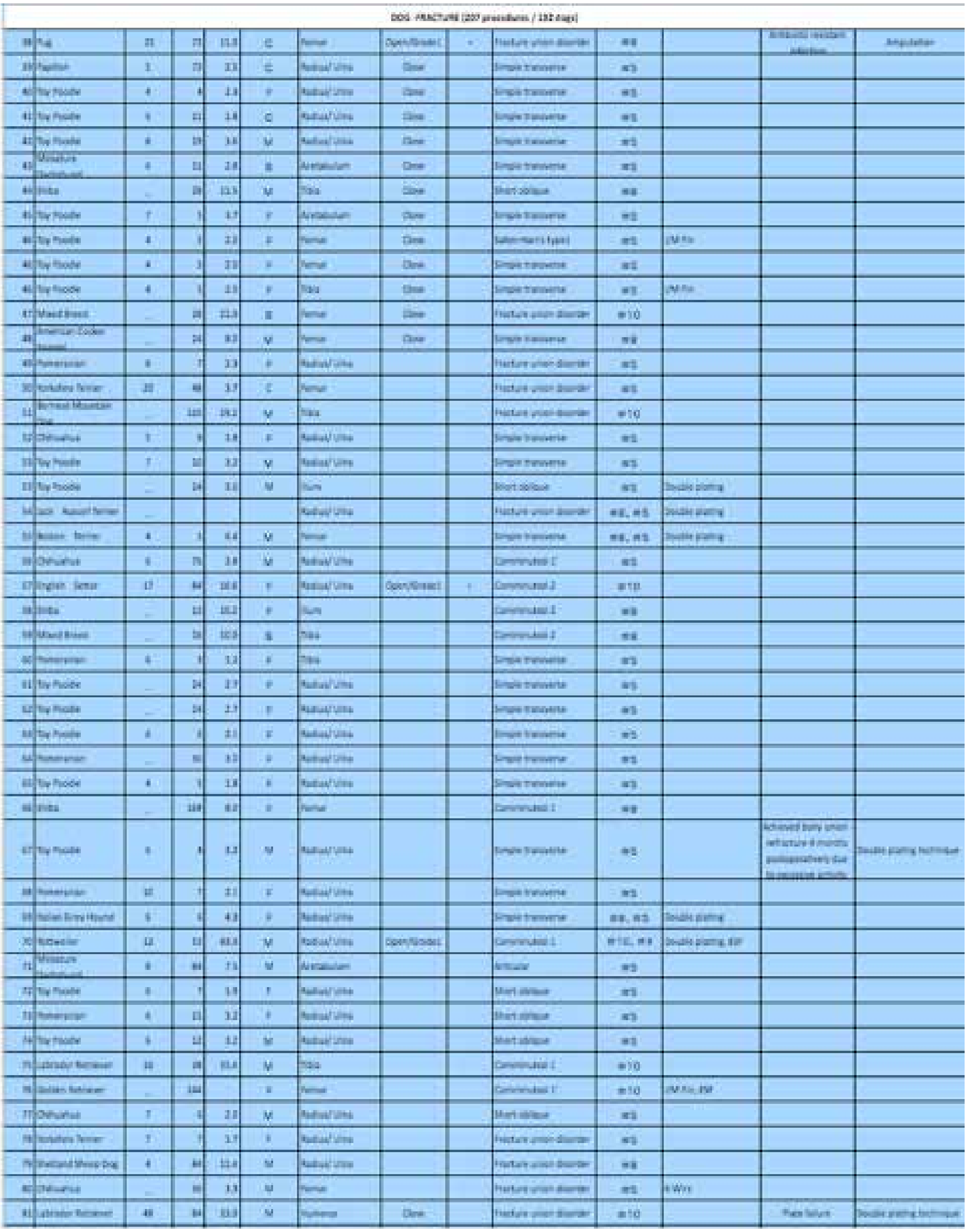
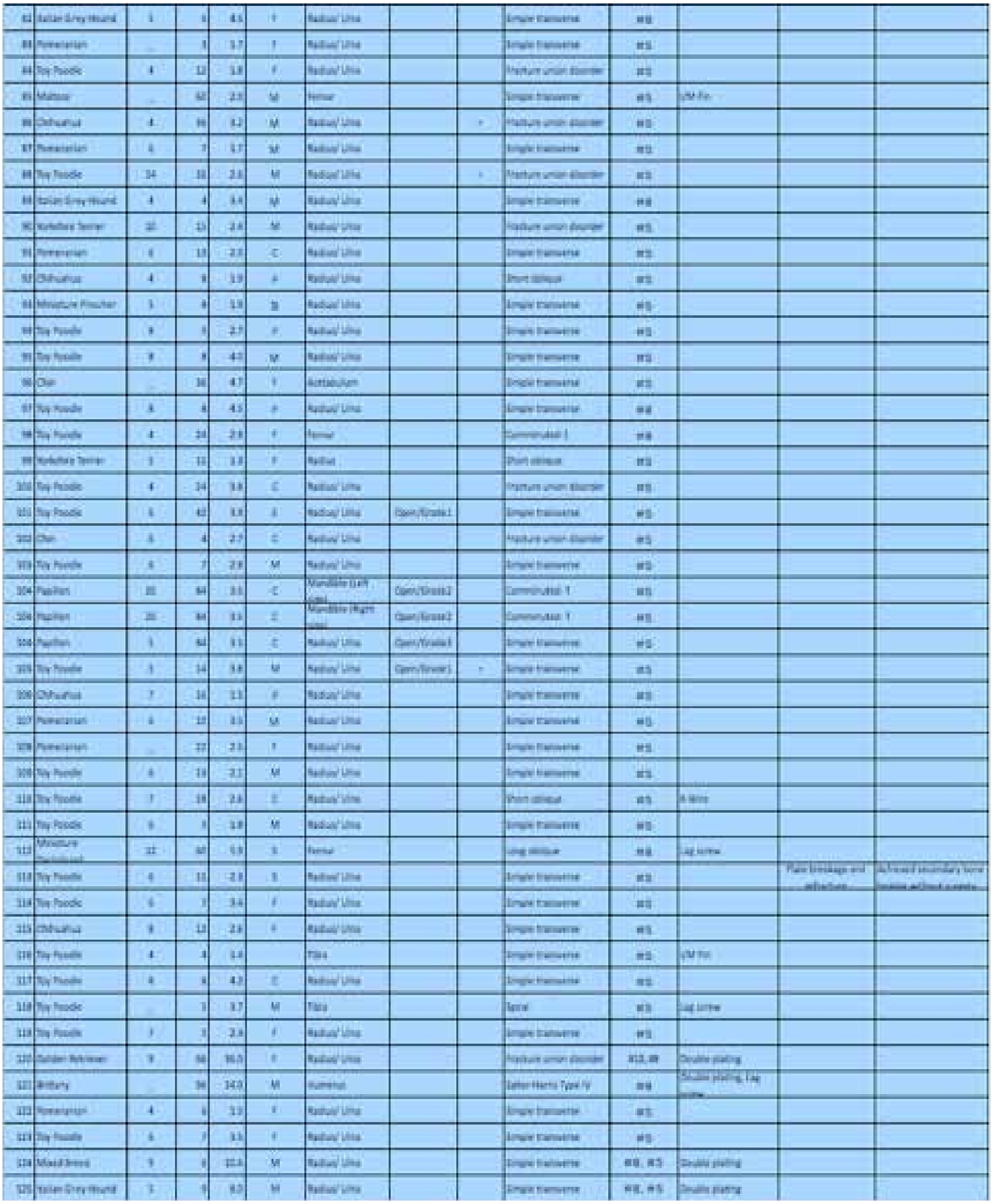


***Table 1.** Continued*



DOG - FRACTURE (207 procedures / 192 dogs)													
38	Pug	21	73	11.0	C	Femur	Open/Grade1	-	Fracture union disorder	#8		Antibiotic resistant infection	Amputation
39	Papillon	1	73	2.5	C	Radius/ Ulna	Close		Simple transverse	#5			
40	Toy Poodle	4	4	2.3	F	Radius/ Ulna	Close		Simple transverse	#5			
41	Toy Poodle	5	11	1.8	C	Radius/ Ulna	Close		Simple transverse	#5			
42	Toy Poodle	6	19	3.6	M	Radius/ Ulna	Close		Simple transverse	#5			
43	Miniature Dachshund	4	11	2.8	S	Acetabulum	Close		Simple transverse	#5			
44	Shiba	_	28	11.5	M	Tibia	Close		Short oblique	#8			
45	Toy Poodle	7	5	3.7	F	Acetabulum	Close		Simple transverse	#5			
46	Toy Poodle	4	3	2.2	F	Femur	Close		Salter-Harris type I	#5	IM Pin		
46	Toy Poodle	4	3	2.0	F	Femur	Close		Simple transverse	#5			
46	Toy Poodle	4	3	2.5	F	Tibia	Close		Simple transverse	#5	IM Pin		
47	Mixed Breed	_	28	11.3	S	Femur	Close		Fracture union disorder	#10			
48	American Cocker Spaniel	_	24	8.0	M	Femur	Close		Simple transverse	#8			
49	Pomeranian	8	7	2.3	F	Radius/ Ulna			Fracture union disorder	#5			
50	Yorkshire Terrier	20	48	3.7	C	Femur			Fracture union disorder	#5			
51	Bernese Mountain Dog	_	120	29.2	M	Tibia			Fracture union disorder	#10			
52	Chihuahua	7	9	1.8	F	Radius/ Ulna			Simple transverse	#5			
53	Toy Poodle	7	10	3.2	M	Radius/ Ulna			Simple transverse	#5			
53	Toy Poodle	_	24	3.1	M	Ilium			Short oblique	#5	Double plating		
54	Jack Russell Terrier	_				Radius/ Ulna			Fracture union disorder	#8, #5	Double plating		
55	Boston Terrier	4	3	4.4	M	Femur			Simple transverse	#8, #5	Double plating		
56	Chihuahua	5	75	3.8	M	Radius/ Ulna			Comminuted 2	#5			
57	English Setter	17	84	18.6	F	Radius/ Ulna	Open/Grade1	I	Comminuted 2	#10			
58	Shiba	_	12	10.2	F	Ilium			Comminuted 2	#8			
59	Mixed Breed	_	16	10.0	S	Tibia			Comminuted 2	#8			
60	Pomeranian	6	9	1.2	F	Tibia			Simple transverse	#5			
61	Toy Poodle	_	24	2.7	F	Radius/ Ulna			Simple transverse	#5			
62	Toy Poodle	_	24	2.7	F	Radius/ Ulna			Simple transverse	#5			
63	Toy Poodle	6	8	2.1	F	Radius/ Ulna			Simple transverse	#5			
64	Pomeranian	_	90	3.0	F	Radius/ Ulna			Simple transverse	#5			
65	Toy Poodle	4	5	1.8	F	Radius/ Ulna			Simple transverse	#5			
66	Shiba	_	108	8.0	F	Femur			Comminuted 1	#8			
67	Toy Poodle	6	6	3.2	M	Radius/ Ulna			Simple transverse	#5		Achieved bony union - refracture 4 months postoperatively due to excessive activity	Double plating technique
68	Pomeranian	10	7	2.1	F	Radius/ Ulna			Simple transverse	#5			
69	Italian Grey Hound	5	6	4.8	F	Radius/ Ulna			Simple transverse	#8, #5	Double plating		
70	Rottweiler	12	12	43.6	M	Radius/ Ulna	Open/Grade1		Comminuted 1	#10, #8	Double plating, ESF		
71	Miniature Dachshund	8	84	7.5	M	Acetabulum			Articular	#5			
72	Toy Poodle	6	7	1.9	F	Radius/ Ulna			Short oblique	#5			
73	Pomeranian	6	11	3.2	F	Radius/ Ulna			Short oblique	#5			
74	Toy Poodle	5	12	3.2	M	Radius/ Ulna			Short oblique	#5			
75	Labrador Retriever	16	28	33.4	M	Tibia			Comminuted 1	#10			
76	Golden Retriever	_	144		F	Femur			Comminuted 1	#10	IM Pin, ESF		
77	Chihuahua	7	6	2.0	M	Radius/ Ulna			Short oblique	#5			
78	Yorkshire Terrier	7	7	1.7	F	Radius/ Ulna			Fracture union disorder	#5			
79	Shetland Sheep Dog	8	84	11.6	M	Radius/ Ulna			Fracture union disorder	#8			
80	Chihuahua	_	90	3.5	M	Femur			Fracture union disorder	#5	K-Wire		
81	Labrador Retriever	48	84	33.0	M	Humerus	Close		Fracture union disorder	#10		Plate failure	Double plating technique

Table 1. *Continued*



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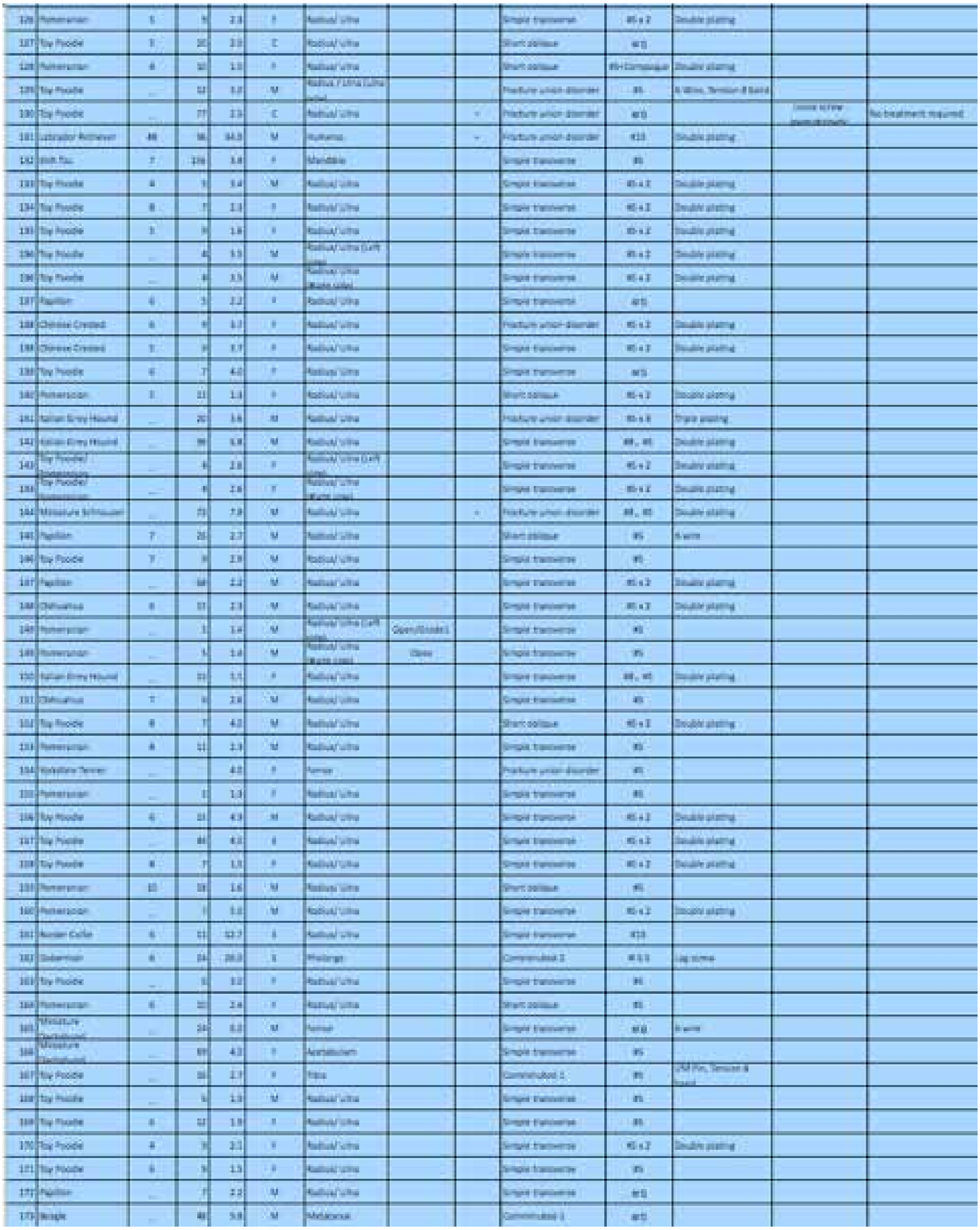
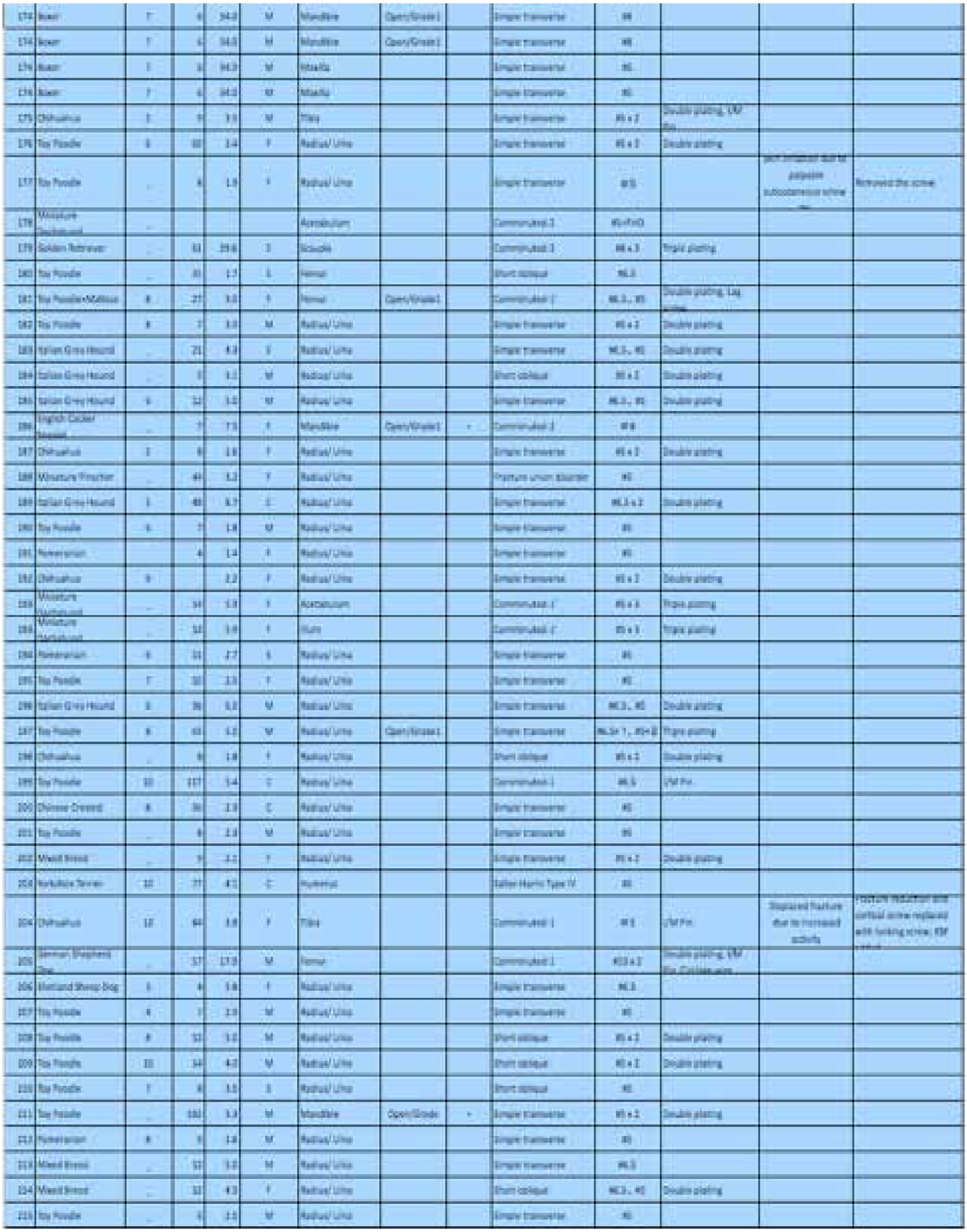


126	Pomeranian	5	9	2.3	F	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
127	Toy Poodle	3	10	2.0	C	Radius/ Ulna			Short oblique	#1.5			
128	Pomeranian	4	10	1.5	F	Radius/ Ulna			Short oblique	#5+Compaque	Double plating		
129	Toy Poodle	…	12	3.0	M	Radius / Ulna (Ulna Side)			Fracture union disorder	#5	K-Wire, Tension Band		
130	Toy Poodle	…	77	2.5	C	Radius/ Ulna		-	Fracture union disorder	#1.5		Loose screw	No treatment required
131	Labrador Retriever	48	96	34.0	M	Humerus		-	Fracture union disorder	#15	Double plating		
132	Shih Tzu	7	106	3.8	F	Mandible			Simple transverse	#5			
133	Toy Poodle	4	9	3.4	M	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
134	Toy Poodle	8	7	2.3	F	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
135	Toy Poodle	3	9	1.8	F	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
136	Toy Poodle	…	4	3.5	M	Radius/ Ulna (Left side)			Simple transverse	#5 x 2	Double plating		
136	Toy Poodle	…	4	3.5	M	Radius/ Ulna (Right side)			Simple transverse	#5 x 2	Double plating		
137	Papillon	6	3	2.2	F	Radius/ Ulna			Simple transverse	#1.5			
138	Chinese Crested	6	9	3.7	F	Radius/ Ulna			Fracture union disorder	#5 x 2	Double plating		
138	Chinese Crested	5	9	3.7	F	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
139	Toy Poodle	6	7	4.0	F	Radius/ Ulna			Simple transverse	#1.5			
140	Pomeranian	3	11	1.3	F	Radius/ Ulna			Short oblique	#5 x 2	Double plating		
141	Italian Grey Hound	…	20	3.6	M	Radius/ Ulna			Fracture union disorder	#5 x 3	Triple plating		
142	Italian Grey Hound	…	99	5.8	M	Radius/ Ulna			Simple transverse	#8 , #5	Double plating		
143	Toy Poodle/ Pomeranian	…	6	2.8	F	Radius/ Ulna (Left side)			Simple transverse	#5 x 2	Double plating		
143	Toy Poodle/ Pomeranian	…	6	2.8	F	Radius/ Ulna (Right side)			Simple transverse	#5 x 2	Double plating		
144	Miniature Schnauzer	…	71	7.8	M	Radius/ Ulna		-	Fracture union disorder	#8 , #5	Double plating		
145	Papillon	7	26	2.7	M	Radius/ Ulna			Short oblique	#5	K-wire		
146	Toy Poodle	7	9	2.9	M	Radius/ Ulna			Simple transverse	#5			
147	Papillon	…	68	2.2	M	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
148	Chihuahua	8	11	2.3	M	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
149	Pomeranian	…	3	1.4	M	Radius/ Ulna (Left side)	Open/Grade1		Simple transverse	#5			
149	Pomeranian	…	5	1.4	M	Radius/ Ulna (Right side)	Close		Simple transverse	#5			
150	Italian Grey Hound	…	11	5.1	F	Radius/ Ulna			Simple transverse	#8 , #5	Double plating		
151	Chihuahua	7	8	2.8	M	Radius/ Ulna			Simple transverse	#5			
152	Toy Poodle	8	7	4.2	M	Radius/ Ulna			Short oblique	#5 x 2	Double plating		
153	Pomeranian	8	11	2.3	M	Radius/ Ulna			Simple transverse	#5			
154	Yorkshire Terrier	…		4.0	F	Femur			Fracture union disorder	#5			
155	Pomeranian	…	7	1.3	F	Radius/ Ulna			Simple transverse	#5			
156	Toy Poodle	6	10	4.3	M	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
157	Toy Poodle	…	40	4.0	F	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
158	Toy Poodle	8	7	1.5	F	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
159	Pomeranian	10	18	1.6	M	Radius/ Ulna			Short oblique	#5			
160	Pomeranian	…	7	3.0	M	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
161	Border Collie	6	11	12.7	F	Radius/ Ulna			Simple transverse	#10			
162	Doberman	6	14	28.0	C	Phalange			Comminuted 1	#1.5	Lag screw		
163	Toy Poodle	…	5	3.0	F	Radius/ Ulna			Simple transverse	#5			
164	Pomeranian	6	10	2.4	F	Radius/ Ulna			Short oblique	#5			
165	Miniature Dachshund	…	14	5.0	M	Femur			Simple transverse	#8	K-wire		
166	Miniature Dachshund	…	69	4.0	F	Acetabulum			Simple transverse	#5			
167	Toy Poodle	…	16	2.7	F	Tibia			Comminuted 1	#5	IM Pin, Tension Band		
168	Toy Poodle	…	6	1.5	M	Radius/ Ulna			Simple transverse	#5			
169	Toy Poodle	6	12	1.9	F	Radius/ Ulna			Simple transverse	#5			
170	Toy Poodle	4	9	2.1	F	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
171	Toy Poodle	6	9	1.5	F	Radius/ Ulna			Simple transverse	#5			
172	Papillon	…	7	2.2	M	Radius/ Ulna			Simple transverse	#1.5			
173	Beagle	…	48	5.8	M	Metacarpal			Comminuted 1	#1.5			

Table 1. Continued



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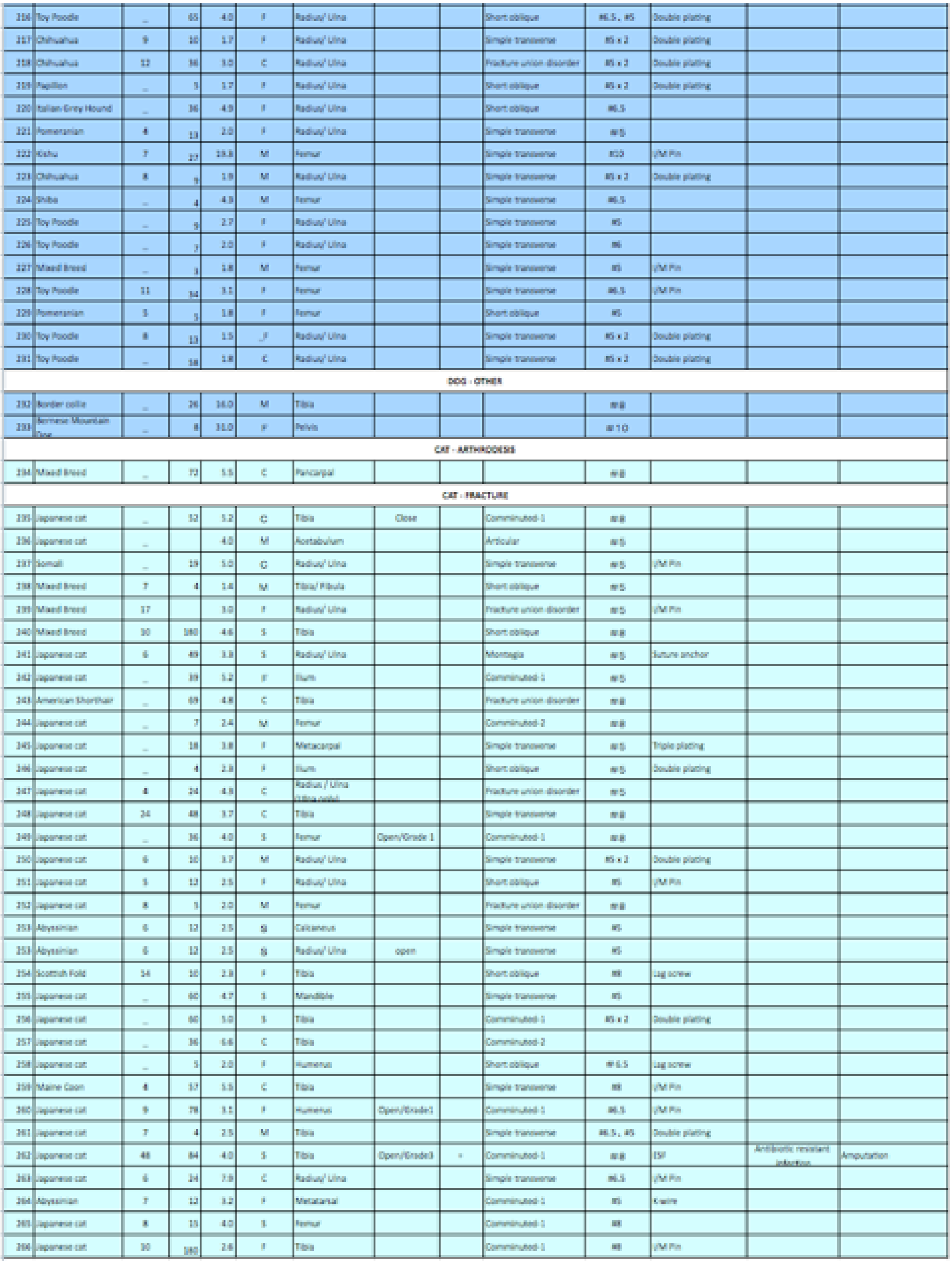


216	Toy Poodle	_	65	4.0	F	Radius/ Ulna			Short oblique	#6.5 , #5	Double plating		
217	Chihuahua	9	10	1.7	F	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
218	Chihuahua	12	36	3.0	C	Radius/ Ulna			Fracture union disorder	#5 x 2	Double plating		
219	Papillon	_	5	1.7	F	Radius/ Ulna			Short oblique	#5 x 2	Double plating		
220	Italian Grey Hound	_	36	4.9	F	Radius/ Ulna			Short oblique	#6.5			
221	Pomeranian	4	13	2.0	F	Radius/ Ulna			Simple transverse	#5			
222	Kishu	7	27	19.8	M	Femur			Simple transverse	#10	I/M Pin		
223	Chihuahua	8	9	1.9	M	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
224	Shiba	_	4	4.3	M	Femur			Simple transverse	#6.5			
225	Toy Poodle	_	9	2.7	F	Radius/ Ulna			Simple transverse	#5			
226	Toy Poodle	_	7	2.0	F	Radius/ Ulna			Simple transverse	#6			
227	Mixed Breed	_	3	1.8	M	Femur			Simple transverse	#5	I/M Pin		
228	Toy Poodle	11	34	3.1	F	Femur			Simple transverse	#6.5	I/M Pin		
229	Pomeranian	5	5	1.8	F	Femur			Short oblique	#5			
230	Toy Poodle	8	13	1.5	_F	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
231	Toy Poodle	_	18	1.8	C	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
DOG - OTHER													
232	Border collie	_	26	16.0	M	Tibia				#8			
233	Bernese Mountain Dog	_	8	31.0	F	Pelvis				# 10			
CAT - ARTHRODESIS													
234	Mixed Breed	_	72	5.5	C	Pancarpal				#8			
CAT - FRACTURE													
235	Japanese cat	_	12	5.2	C	Tibia	Close		Comminuted-1	#8			
236	Japanese cat	_		4.0	M	Acetabulum			Articular	#5			
237	Somali	_	19	5.0	C	Radius/ Ulna			Simple transverse	#5	I/M Pin		
238	Mixed Breed	7	4	1.4	M	Tibia/ Fibula			Short oblique	#5			
239	Mixed Breed	17		3.0	F	Radius/ Ulna			Fracture union disorder	#5	I/M Pin		
240	Mixed Breed	10	180	4.6	S	Tibia			Short oblique	#8			
241	Japanese cat	6	49	3.8	S	Radius/ Ulna			Montegia	#5	Suture anchor		
242	Japanese cat	_	39	5.2	F	Ilium			Comminuted-1	#5			
243	American Shorthair	_	69	4.8	C	Tibia			Fracture union disorder	#8			
244	Japanese cat	_	7	2.4	M	Femur			Comminuted-2	#8			
245	Japanese cat	_	18	3.8	F	Metacarpal			Simple transverse	#5	Triple plating		
246	Japanese cat	_	4	2.8	F	Ilium			Short oblique	#5	Double plating		
247	Japanese cat	4	24	4.8	C	Radius / Ulna (Ulna only)			Fracture union disorder	#5			
248	Japanese cat	24	48	3.7	C	Tibia			Simple transverse	#8			
249	Japanese cat	_	36	4.0	S	Femur	Open/Grade 1		Comminuted-1	#8			
250	Japanese cat	6	10	3.7	M	Radius/ Ulna			Simple transverse	#5 x 2	Double plating		
251	Japanese cat	5	12	2.5	F	Radius/ Ulna			Short oblique	#5	I/M Pin		
252	Japanese cat	8	5	2.0	M	Femur			Fracture union disorder	#8			
253	Abyssinian	6	12	2.5	S	Calcaneus			Simple transverse	#5			
253	Abyssinian	6	12	2.5	S	Radius/ Ulna	open		Simple transverse	#5			
254	Scottish Fold	14	10	2.8	F	Tibia			Short oblique	#8	Lag screw		
255	Japanese cat	_	60	4.7	S	Mandible			Simple transverse	#5			
256	Japanese cat	_	60	5.0	S	Tibia			Comminuted-1	#5 x 2	Double plating		
257	Japanese cat	_	36	6.6	C	Tibia			Comminuted-2				
258	Japanese cat	_	5	2.0	F	Humerus			Short oblique	# 6.5	Lag screw		
259	Maine Coon	4	17	5.5	C	Tibia			Simple transverse	#8	I/M Pin		
260	Japanese cat	9	78	3.1	F	Humerus	Open/Grade1		Comminuted-1	#6.5	I/M Pin		
261	Japanese cat	7	4	2.5	M	Tibia			Simple transverse	#6.5 , #5	Double plating		
262	Japanese cat	48	84	4.0	S	Tibia	Open/Grade3	+	Comminuted-1	#8	ESF	Antibiotic resistant infection	Amputation
263	Japanese cat	6	24	7.9	C	Radius/ Ulna			Simple transverse	#6.5	I/M Pin		
264	Abyssinian	7	12	3.2	F	Metatarsal			Comminuted-1	#5	K-wire		
265	Japanese cat	8	15	4.0	S	Femur			Comminuted-1	#8			
266	Japanese cat	10	180	2.6	F	Tibia			Comminuted-1	#8	I/M Pin		

failed to heal. Of the 61 preoperative culture cases, 11 were treated with antibiotics based on susceptibility results. Bone union was unsuccessful in two of the cases found with infection at the time of surgery.In both cases, MRSA was detected, and when infection control failed, amputations were performed. For the remaining 180 dogs and 25 cats in which infection was considered unlikely, bacterial culture was not performed. Only one of these cases resulted in a postoperative infection.

With the exception of the two amputations, all treated cases achieved bone union or, for those cases in which union was not complete at the end of this study, a progression towards bone union, as indicated by radiographic evidence of callus formation. Double (n=72) or triple (n=6) plating technique was used in 78 cases (Tables 1 and 3). Additional fixation, including cerclage, lag screw, IM pin, tension 8 band, and/or external skeletal fixation, was implemented in another 35 cases.

Complications

Intraoperative complications were reported in 10 animals, including 1 stripped screw head and 9 screw fractures. Postoperative complications were reported in 9 of the 282 procedures (3.2%), including 7 (2.5%) major postoperative complications and 2 (0.7%) minor postoperative complications. Of the nine postoperative complications, four resulted from implant failure (plate breakage or loosening of a screw), and five were biological failure (infection or refracture).

Five patients with major postoperative complications, including two radioulnar fractures, one radioulnar corrective osteotomy, one humeral fracture and one comminuted tibial fracture, required a second surgery. Bone union was achieved in all five cases, and all patients made a full functional recovery. Two patients with antibiotic resistant infections resulted in amputation. The two postoperative cases with minor complications that received no additional surgical intervention were both radioulnar fractures. Postoperative complication details and resolutions are summarized in Table 1.

Two cases required amputation; each presented with a local infection at the fracture site after a previous reduction attempt at a referring institution. In both cases, fracture reduction was attempted at the owners urging, despite advice that bone union was unlikely. In each case, methicillin-resistant Staphylococcus aureus (MRSA), and additionally in one case, pseudomonas aeruginosa, was detected by culture and amputation was indicated.

DISCUSSION

This retrospective study was initiated to evaluate the clinical application of the Advanced Locking Plate System (ALPS) as an alternative to the more conventional Dynamic Compression Plate (DCP) System in small animal orthopedics. Our results with ALPS demonstrated a high rate of bone union or progression toward bone union (99.3%), with low postoperative complications (3.2%).

Until the introduction of internal fixators, fracture stability relied on the friction provided by the screws between the bone plate and the bone, resulting in a compression of the plate to the bone (Perren, 2002; Voss, et al, 2009). Internal fixators, such as PC-Fix, rely on splinting the fragments of a fracture internally with locking bolts so that the blood supply is not compromised by compression of the periosteum (Eijer, et al, 2001). ALPS has not been tested experimentally in vivo, nor has it been tested in a clinical trial. However, the limited bone contact and fixation method are similar to PC-Fix, suggesting that observations from the PC-Fix project are relevant to ALPS. Separate in vitro testing of the ALPS 10 plate showed a 20% higher bending strength than stainless steel (DCP 3.5), validating the design process (Blake, et al, 2011). Following approximately 8 years of animal testing, advantages of PC-Fix over conventional plating include a significantly increased resistance to infection, reduced impact on bone remodeling, and faster, more consistent healing (Tepic, et al, 1997; Haas, et al., 2001; Hertel, et al,

Table 2. *Procedure by Type of Fixation and Location*

Location	Localization (% total of 240 fractures)	Dogs (Fractures/ Animals)	Cats (Fractures/ Animals)	Patient age range (months)	Patient mean age (months)	Patient body weight range (kg)	Patient mean body weight (kg)	Diaphyseal (N)	Metaphyseal (N)
Fractures									
Humerus	2.5%	4	2	5 – 96	81	2.0 – 34.0	9.0	4 (67%)	2 (33%)
Radius / Ulna	64.6%	147	8	4 – 117	4	1.0 – 43.0	2.7	123 (81%)	29 (19%)
Femur	11.3%	23	4	3 – 168	27	1.7 – 21.0	4.0	25 (92%)	2 (8%)
Tibia	9.6%	11	12	3 – 180	36	1.2 – 35.4	3.9	21 (91%)	2 (9%)
Acetabular	3.3%	7	1	5 – 89	25	2.8 – 7.5	4.0		
Illial	2.1%	3	2	4 – 39	14	2.3 – 10.2	5.2		
Mandibular	3.3%	7	1	6 – 192	60	3.3 – 34.0	4.7		
Maxilla	0.8%	2	-	6	6	34.0	34.0		
Metatarsal	0.8%	1	1	12 – 48	30	3.2 – 9.8	6.5		
Metacarpal	0.4%	-	1	18	18	3.8	3.8		
Phalanges	0.4%	1	-	24	24	26.0	26.0		
Calcaneus	0.4%	-	1	12	12	2.5	2.5		
Scapula	0.4%	1	-						
Total Fractures / Animals		**207 / 194**	**33 / 32**						
Corrective Osteotomies									
Femoral		15	-	5 – 88	11	1.0 – 21.5	6.0		
Radial		9	-	11 – 96	31	2.8 – 10.6	4.5		
Tibial		2		6 – 7	6.5	3.3 – 4.4	3.9		
Total Osteotomies / Animals		**26 / 24**	**0**						
Arthrodesis									
Tarsal		7	-	24 – 120	72	3.0 – 15.8	10.0		
Carpal		3	1	55 – 84	63.5	3.0 – 10.3	6.4		
Shoulder		2	-	10 – 72	41	3.4 – 3.5	3.5		
Elbow		1	-	97	97	5.0	5.0		
Total Arthrodesis / Animals		**13 / 13**	**1 / 1**						
Other									
Preventive (TTA)		1	-						
Triple Pelvic Osteotomy revision		1	-						
Total Fractures / Animals		**248 / 233**	**34 / 33**						
Total Fractures / Animals	**282 / 266**								

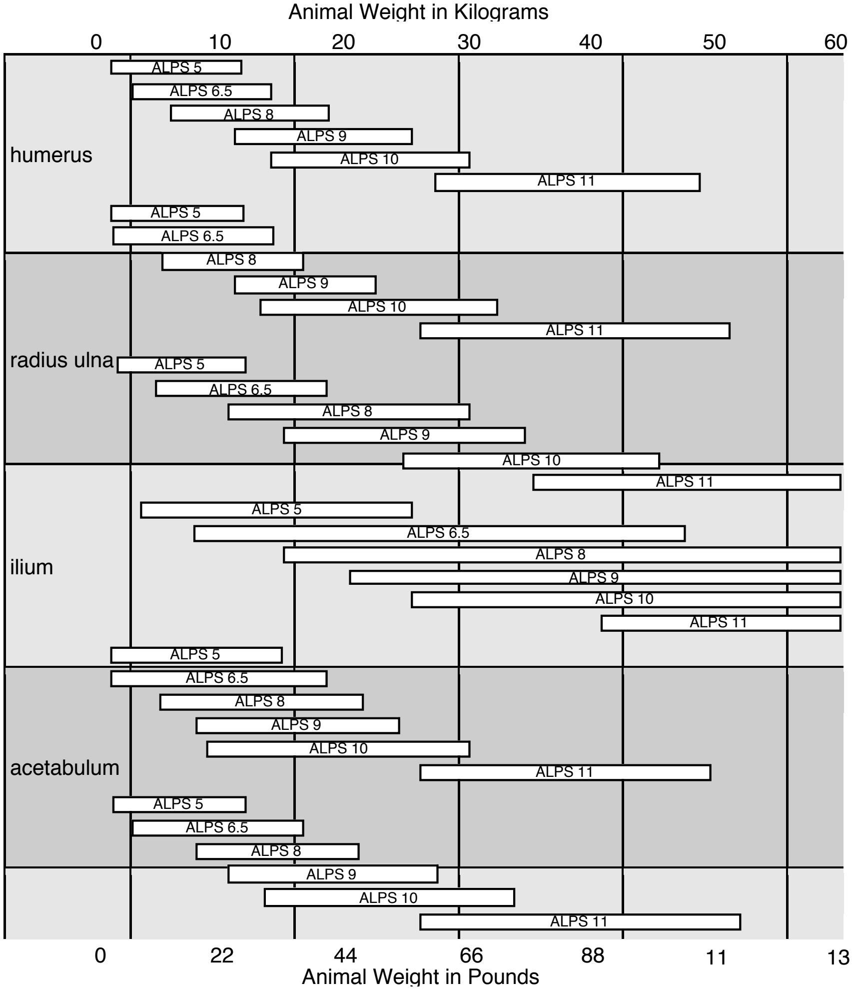
2001).

The intent of biological internal fixation, for which ALPS is particularly amenable, is to minimize damage to the surrounding soft tissue by using indirect reduction, thereby avoiding the increased bone exposure required by exact reduction (Perren, 2002). To maintain stability, an internal fixator relies on locking the screws in the plate rather than on compression and friction between

***Table 3.** Fracture Type and Additional Fixation*

Location	Fracture Type	N (Fracture number)	Additional Fixation	N
Humerus	Short oblique	1	Lag screw	2
	Salter-Harris Type 4	2	I/M pin	1
	Comminuted -1	1		
	Fracture union disorder	2		
Total		6		3
Radius / Ulna	Simple transverse	106	Ulnar I/M pin	5
	Short oblique	24	Ulnar I/M pin + tension 8 band	1
	Comminuted-1	2	K-wire	2
	Comminuted-1'	1	External skeletal fixation	1
	Comminuted-2	1		
	Montegia	1		
	Fracture union disorder	20		
	Corrective osteotomy	9		
Total		164		9
Femur	Simple transverse	9	I/M pin	5
	Short oblique	2	I/M pin + cerclage wire	1
	Salter-Harris Type 4	1	K-wire	2
	Comminuted-1	5	Lag screw	2
	Comminuted-1'	2		
	Comminuted-2	1		
	Long oblique	1		
	Fracture union disorder	6		
	Corrective osteotomy	15		
Total		42		10
Tibia	Simple transverse	7	Lag screw	2
	Short oblique	4	I/M pin	6
	Comminuted-1	7	External skeletal fixation	1
	Comminuted-2	2		
	Spiral	1		
	Fracture union disorder	2		
	Corrective osteotomy	2		
Total		25		9
Other Fracture Location	Acetabular	8		
	Illial	5		
	Mandibular	8		
	Maxilla	2		
	Metatarsal	2	K-wire	1
	Metacarpal	1		
	Phalange	1	Lag screw	1
	Calcaneus	1		
	Scapula	1		
Total		29		2

Figure 1. *Implant Reference Chart*



the plate and the bone (Perren, 2002). In this study, none of the treated animals had a detectable radiographic decrease in bone density under the plate.

Implant material, implant design and/or surgical technique may each play crucial roles in the prevention of infection (Schlegel, et al, 2006). It has been suggested that an implant material with increased biocompatibility, such as titanium, may reduce susceptibility to local infection (Matter, et al, 1990; Pascual, et al, 1992). One investigation concluded that stainless steel may play a role in the inhibition of polymorphonuclear leukocytes superoxide production, resulting in device-related infections (Pascual, et al, 1992). A local bacterial challenge study compared infection rates of stainless steel DCP with titanium DCP in rabbit tibiae; the stainless steel DCP rate (75%) was significantly higher than the titanium DCP rate (35%, $p<0.05$) (Arens, et al, 1996). In the current study, only 3 (1.1%) of 282 fixations resulted in postoperative infection complications, two of which presented with bacterial infection before surgery. The third postoperative infection was believed to be the result of poor plate size selection, resulting in skin necrosis over the plate.

Additionally, bacterial infection risk may be increased with periosteum compression when using DCP. Conversely, minimizing damage to local blood supply, thereby preserving the vitality of the underlying bone, may reduce infection risk. Bone loss seen near conventional implants was originally attributed to unloading or stress shielding of the bone (Perren, 2002). Several papers have suggested that preservation of bone fragment viability and soft tissue immediately deep to the plate was key to unimpaired fracture healing using internal fixators (Rittmann, et al, 1974; Gautier, et al, 1992; Fernández Dell'Oca, et al, 2001). ALPS follows this principle by combining two unique features. First, the underside of the ALPS plate allows only very small contact areas with the bone, thereby reducing periosteal blood supply occlusion. Second, the use of locking screws minimizes required drilling depth, thereby limiting vascular damage within the medullary canal.

A local bacterial challenge study plated 38 intact rabbit tibiae using either titanium DCP or PC-Fix; infection occurred in 12 of the DCP and 5 of the PC-Fix tibiae ($p=0.022$) (Eijer, et al, 2001). The periosteum saving geometry of ALPS plates makes them especially suitable for double plating when extra strength is required, as bone under the plate is not compromised by occluded perfusion. Double or triple plating is an acceptable alternative to using lag screws. In the authors' opinion, this can increase the strength because the plates support each other in the direction where their respective bending is weaker, as well as allowing for additional screws, rendering the device usable in distal fractures. In this retrospective study, of the initial 282 surgeries 78 (27.7%) were treated using a double or triple plating technique. Of those, only one (Case 29) was reported to have postoperative complications.

All 10 intraoperative complications, each involving a 1.5 mm conventional screw failure, occurred within the first year of ALPS use and no such incidents have occurred since. Each of these 10 cases was left untreated, and the screw shaft remained in the bone without incident. Although intended for self tapping, the original ALPS conventional 1.5 mm screws lacked cutting flutes and required high insertion torque in cortical bone. Subsequently, cutting flutes were added and all locking screws were redesigned to reduce the insertion torque by about factor two (presented by Tepic 2010). Currently all ALPS screws, both locking and non-locking, are manufactured from a titanium alloy (TiAI6V4) that is about 50% stronger than c.p. titanium Grade 4 used for plates and, originally, for conventional non-locking screws.

In this study, postoperative complications occurred in 9 of 282 procedures (3.2%), of which 4 (1.4%) were due to implant failure. This complication rate is relatively low when compared to several published studies using both conventional repair and internal fixators (Hunt, et al, 1980; Duhautois, et al, 2003; Reems, et al, 2003; Haaland, et al, 2009). A study using a plate-rod construct for diaphyseal fracture repair in 47 dogs and cats reported a complication rate of 31.9% (15/47 cases) (Reems, et al, 2003). A separate study of 121 dogs and cats with diaphyseal fractures repaired using interlocking nails reported 26 complications (21.5%) (Duhautois, et al, 2003). A clinical experience study reported a complication rate of approximately 11% repairing 47 small animal fractures using a locking compression plate system (Haaland, et al, 2009).

Study investigators believe intraoperative and postoperative complications generally coincide with the necessary adjustment period in learning proper handling techniques required by a new material, in this case, titanium. In particular, titanium is weakened by excessive contouring, especially with reversals of direction. Stainless steel is more tolerant in that respect. Proper plate sizing and double plating options also differ from conventional systems. Two postoperative complications were believed to be related to handling errors. In the first case, poor plate selection resulted in an undersized plate, resulting in a plate failure that may have been avoided using a double-plating technique. In the second case, skin irritation developed over the plate. It is believed that a successful outcome would have been more likely if a smaller plate had been selected. However, the smaller plate size was not available at the time.

Radius and ulna fractures are particularly common in small animals and often result in high complication rates, especially in small breed dogs. Complications can include delayed union, nonunion, malunion, and growth deformities (Rudd, et al, 1992; Voss, et al, 2009). One report on bone plate fixation of 22 distal radius and ulna fractures in 18 small- and miniature-breed dogs reported a 54% complication rate, including 18% catastrophic complications (Larsen, et al, 1999). A separate internal fixation system study on the repair of long-bone fractures in cats and small dogs, reported an overall complication rate of 19.7% (Voss, et al, 2009). In the current study, 92% (140) of the radioulnar fractures occurred in small breed dogs, and of those, only five (3.6%) had reported postoperative complications, a low rate compared to previous studies. Of the reported five postoperative complications in small breed dogs, three (2.1%) were major complications and 2 (1.4%) were minor complications.

A study that may help explain this decreased complication rate in small-breed dogs using ALPS suggested that these dogs have decreased vascular density at the distal diaphyseal-metaphyseal junction compared with large breed dogs. This reduced vascularity was shown to correspond to the region associated with a poor prognosis for fracture healing in small breed dogs (Welch, et al, 1997). The authors suggest that these observations, combined with the previously discussed observation that the key to unimpaired fracture healing is preservation of the periosteal blood supply through minimal contact between the underlying bone and the ALPS plate resulted in the decreased complication rate, particularly in small breed dogs (Rittmann, et al, 1974; Gautier, et al, 1992; Fernández Dell'Oca, et al, 2001).

Although only 13 cases involved arthrodesis. The authors found the ALPS system particularly effective, warranting future investigation. The ALPS system did not result in bone density loss under the plate and rarely induced skin irritation, thereby negating the need for plate removal. In this study, only the first case had a plate removed following bone healing. The authors found ALPS of particular value treating fractures of the distal humerus, femur, tibia, bridging of comminuted fractures and, in particular, acetabular fractures. Because plate bending is easy to achieve and does not require precision, it can be readily applied to the acetabulum's unusual anatomical features. Of course, as stated previously, repeated contouring may weaken the plate.

CONCLUSIONS

This retrospective study successfully establishes the usefulness of the ALPS plating system for the stabilization of a variety of fracture types, arthrodeses, and corrective osteotomies in small animal orthopedics, while simultaneously demonstrating a low postoperative complication rate.

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