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Biomechanical evaluation of simulated feline patella fracture repairs

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Conflict of Interest

There are no conflicts of interest in this study.

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1 Introduction

Patellar fractures in cats have been reported infrequently in the veterinary literature 2 (1, 2), but a recent report presented a survey of 34 cats with 52 patellar fractures (3). 3 The fractures consistently occurred in the proximal half with transverse configuration 4 and sclerosis at the fracture site, suggestive of stress fracture(4). Radiographic union 5 is rare, though has been documented in three cases (5, 6). Complications after 6 surgical repair were found to be common, with 86% of cases managed with pin and 7 tension band wire failing (3), however, insufficient numbers of other repair methods 8 9 were compared in this study to allow assessment of alternative techniques. A recent paper suggested that conservative management was associated with a good 10 prognosis (6), although this also reported very few cases, with no long term evaluation. 11 In the authors' opinion, many animals have a varying degree of ongoing lameness and 12 13 reduced hindlimb function (e.g. inability to jump).

Patellar fractures in humans are relatively common, accounting for 1% of all fractures 14 (7). The commonest fracture configuration in humans is transverse, usually due to 15 trauma, although stress fractures are also reported (4). In human orthopaedics, a large 16 number of fixation methods for patellar fractures have been described (7-14). 17 Historically, the most favoured technique has been pin and tension band fixation, 18 though implant related complications are common with this technique (15). The size 19 of the fracture gap and motion at the fracture site are important considerations for 20 fixation, with excessive motion leading to high levels of strain which impedes bone 21 healing. Interfragmentary gap is dependent upon compression achieved during 22 fixation and the stability of the construct (16). 23

Several biomechanical studies for patellar fracture repair in humans have been 24 reported (7, 10, 11, 16-22). In general, techniques involving fixation into bone such as 25 pin and tension band wiring or screw fixation have been recommended based on these 26 studies, however a recent report found good clinical results with combined 27 circumferential and tension band wiring (23). Pin and tension band wiring has been 28 recommended in small animals (24) which may not be appropriate in felines that may 29 have underlying bone pathology. In addition, many repair techniques documented in 30 humans are not possible in felids due to the small size of the patella. 31

Only one biomechanical study of patellar fractures has been published in the peer reviewed veterinary literature(25). This study compared the use of a prototype locking plate with pin and tension band wire and concluded that pin and tension band wiring was an unsuitable method in the dog. Our aim was to compare the biomechanical strength of the repair construct generated by different repair methods, using a cadaveric model of feline patellar fracture. Knowledge of repair strength using different methods will help decision making in future clinical cases.(16)

39 Materials and methods

Pelvic limbs were collected from young adult to middle aged cats (age estimated based on clinical examination), mean body weight 3.75Kg (2.45-5.74Kg) that were euthanatized or died for reasons unrelated to orthopaedic disease. CT imaging was performed on all limbs to ensure they were free of orthopaedic disease. The limbs were stored at -20°C then thawed gradually in a cold room.

The soft tissue on the tibia and caudal aspect of the femur was removed leaving the extensor mechanism intact. The quadriceps muscle was freed from the underlying bone. Care was taken to preserve the joint capsule and ligaments around the stifle.

The patellae were measured with Vernier callipers and the level of the proximal 35% calculated. The bone was cut at this level using an oscillating saw (Depuy Synthes Colibri II with sagittal saw attachment) fitted with a 0.4mm blade. The medial and lateral retinaculae were divided by scalpel to simulate a displaced fracture.

The femur was cut transversely at 50% of its length measured from the proximal greater trochanter to distal aspect of the lateral condyle. The medullary cavity was filled with dental cement and an Ellis pin (4.5mm) driven into the distal femur. The fracture was repaired using one of four methods: Group A–Circumferential wire, Group B–Figure eight wire, Group C–Combined circumferential and figure eight wire, Group D–Pin and tension band wire (Fig 1).

Legs were assigned to groups by block randomisation with 10 legs in each group. All legs were treated independently. A lateral arthrotomy was performed in each case to assess reduction and ensure congruity of the articular surface and to replicate surgery in a clinical case. Once the fracture was stabilised the patella retinaculae were sutured with 2-0 (3m) polyglactin 910 (Vicryl®) in a simple interrupted pattern to aid stability,

with the first sutures placed as close as possible to the patella. The arthrotomy was 63 closed with 2-0 (3m) polyglactin 910 (Vicryl[®]) in a simple continuous pattern. Markers 64 were glued to the cranial surface of the patella adjacent to the osteotomy as a 65 reference point for measurements to be made during video analysis. All wire loops 66 utilised 0.8mm (20 gauge) stainless steel orthopaedic wire. All limbs were tested on a 67 custom jig fitted to the testing platform of a materials testing machine (Instron 3367) 68 with 10kN static load cell). This held the stifle at 135° flexion to simulate a normal 69 weight bearing angle (Fig2) and was positioned such that the patella was pulled up 70 71 the femoral trochlea (26). The femoral intramedullary pin was clamped in position so that any proximal pull on the tibia was resisted by the femur. 72

The quadriceps was then fitted into a clamp through which needles were passed to give increased grip on the muscle belly. To attempt to simulate forces on the fracture experienced in a cage rested cat, the stifles were loaded for 1000 cycles between 5N and 50N at 0.1Hz and the fracture site filmed for the first five and last five cycles to assess changes at the fracture gap.

After cyclic testing, the repairs were adjusted if fragment distraction or movement had occurred to ensure that all repairs were being tested from the same start point for the next stage of testing. The clamp was cooled in liquid nitrogen prior to securing the quadriceps, and the repair tested to failure. Failure was defined as an increase in fracture gap of 3mm (26), as indicated by the markers.

Tests were recorded using a video camera (Kodak PlaySport Zx5, 720p, 60fps) and 83 analysed using video editing software (Pinnacle Studio 20[™]). A ruler was included in 84 the field of view adjacent to the patella and equidistant from the camera. A 85 measurement marker was created from the ruler for each video and this was then used 86 87 to measure the distance between the markers at the start and the end of the experiment. The start measurement was taken prior to the first loading cycle and final 88 measurement at peak loading on the last cycle. For test to failure experiments a timer 89 accurate to 0.1s was included in the field of view. The time in the frame immediately 90 prior to the first instrument movement, and the time when the fracture gap reached 91 3mm as measured from the markers was noted. The difference between the two time 92 points was calculated and this allowed the force at failure to be taken from the 93

instrument log. The recorded extension from the Instron was not adequate, as thisalso includes flexure across the whole tissue unit rather than only at the fracture gap.

96 Surgical technique

97 Group A–Circumferential wire: a 19g needle was passed over the proximal aspect of 98 the proximal fragment and distal aspect of the distal fragment by 'walking-off' the 99 needle lateral to medial. A loop of orthopaedic wire was passed into the tip of each 100 needle and the needles withdrawn. The fragments of patellar were reduced and the 101 wire tightened with care to ensure that over tightening did not occur. Care was also 102 taken to ensure that the wire did not slip caudal to the bone resulting in interference 103 with the articular surface.

Group B–Figure eight wire: a 19g needle was passed under the tendinous attachments of the patella proximally and distally with the needle being passed medial to lateral proximally and lateral to medial distally. The proximal needle was bent slightly prior to placement in order to ease passage around the proximal tissues. The wire was formed into an S-shape and the ends passed into the needle tips. The needles were withdrawn and the distal end of the wire twisted around onto the medial aspect of the stifle. The fragments were reduced and the wire tightened.

Group C–Combined circumferential and figure eight wire: The figure eight wire was placed as described for group B. The circumferential wire was then placed as described for group A ensuring that the needles were placed cranial to the proximal and distal aspect of the figure eight wire to prevent slip caudal to the patella. Wire positioning was such that the twists were on opposite sides of the joint.

Group D–Pin and tension band: A 0.9mm k-wire was drilled through the distal fragment from the centre of the fracture surface distally. The wire was removed and driven back proximally through the hole and into the proximal fragment taking care to ensure accurate alignment of the articular surface. A figure eight tension band wire was placed around the proximal and distal aspects of the pin and tightened.

All of the repairs in this study were performed by a single surgeon (ML).

122 Statistical Analysis

Fracture gap opening after 1000 cycles and force at failure data was analysed using a commercially available statistics analysis software (IBM SPSS statistics for Windows, version 21.0) to compare groups. Data was assessed for normality and analysed using a one-way ANOVA to compare the means between groups with a Tukey post-hoc test. Significance was set as p<.05. Data was presented as mean +/standard deviation (SD).

129 **Results**

130 Mode of failure

The mode of failure in destructive testing was found to be similar between groups A 131 (circumferential wire), B (figure eight wire) and C (combined circumferential and figure 132 eight wire). Group A was observed to have opening of the fracture gap in all cases 133 during the cyclic loading with varying levels of outward (cranial) rotation of the fracture 134 surface. Failure was ultimately caused by fracture fragment rotation, retinacula tearing 135 or tearing of the wire through the soft tissue, or a combination of these factors. One 136 repair from this group failed during cyclic loading due to outward rotation of the fracture 137 138 fragments. Groups B and C failed via one of, or a combination of; retinacula stretching/tearing, wire distortion or wire tearing through distal soft tissue. The mode 139 140 of failure for group D was by distortion of the tension band wire with subsequent pull out of the pin either distally or proximally (3 cases), or by the pin breaking through the 141 142 bone of the distal fragment (6 cases) or proximal fragment (1 case).

143 Cyclic loading

The mean gap opening (+/- SD) at peak load after 1000 cycles for each group was: 144 Group A: 1.66mm (+/- 0.69), Group B: 1.01mm (+/- 0.45), Group C: 0.81mm (+/- 0.58), 145 Group D: 0.65mm (+/- 0.54). Group C and D had statistically lower fracture gap 146 opening after 1000 cycles when compared to group A (p=0.01 and 0.002 respectively). 147 Group B approached statistical significance when compared to group A, but was not 148 149 statistically different from any other group (p=0.07) (Fig. 3). In all but one case in group A, opening at the fracture line of >1mm occurred and resulted in an opening of 3mm 150 151 in one case. Video data showed that there was some tendency for the fragments to pivot around the wire proximally and distally. This led to rotation of the fragments with 152 153 exaggerated opening of the fracture gap (six cases). After cyclic loading, the repair

was adjusted by rotating the fragments back into their original position if necessary.
This was required for five cases in group A. No specimens from other groups required
adjustment.

157 Test to failure

The mean load (+/-SD) at failure in the test to failure analysis were: group A: 171.4 (+/-62.2)N, group B: 208.7 (+/-20.7)N, group C: 288.2 (+/-62.5)N and group D: 219.5 (+/-48.0)N. Group C had statistically higher load to failure than all other groups (p<0.001, p=0.007 and p=0.02 for group A, B and C respectively). There was no difference between other groups (Fig. 4).

163 **Discussion**

164 Our study showed some significant differences when comparing techniques for the 165 fixation of simulated transverse patellar fractures in feline limbs.

A study in humans found that wiring techniques which did not incorporate fixation into 166 bone did not provide sufficient stability for early mobilisation of the limb (18). However, 167 clinical experience in felines (3) has shown that pin and tension band wiring has a high 168 failure rate (86%). This may relate to an underlying bone pathology in cats causing 169 fragility which may not be a consideration in humans. Anecdotal reports exist of the 170 patella fragmenting when drilling is attempted. This was not encountered in the current 171 study but this may reflect the fact that the limbs used were from normal cats. 172 Furthermore, the small size of the patella in cats makes options for fixation into the 173 bone limited. For these reasons we evaluated techniques which did not involve fixation 174 into the bone and rely on the integrity of the soft tissues surrounding the patella. The 175 pin and tension band technique was included to provide a comparison to the previously 176 recommended technique. 177

It was elected to perform cyclic loading between limits of 5-50N. This limit was selected knowing that an average cat weighs approximately 4-5Kg and that strict cage rest would be recommended following surgical repair of patellar fractures. This may however be an underestimate of the force applied in a clinical case depending upon the level of patient activity and size of animal. Opening of the fracture gap with outward rotation of the fracture surface was observed in some stifles in group A following cyclic loading as noted in previous human studies (18). No displacement of fragments was noted with techniques B, C and D.

Groups A, B and C had similar failure modes with elongation of the wire loops and 186 stretching of periarticular soft tissues leading to fracture gap opening. This was likely 187 due to the implants not being directly apposed to the bone and the reliance of these 188 fixation methods on the integrity of the soft tissues (17, 18). Group D was found to 189 have two mechanisms of failure. Initially elongation of the tension band wire loop was 190 noted in both testing modes, but this was accompanied by either sliding of the pin 191 distally through the proximal fragment as the inter-fragmentary gap increased, or by 192 193 the pin cutting through the bone proximally or distally as previously noted (25). It is possible that had thicker wire been utilised then resistance to elongation and reduced 194 195 gap opening would have been observed. The wire chosen in this study was considered to be that most likely to be used in a clinical setting. 196

Accurate and consistent wire placement was technically demanding. This was more 197 difficult for group A than group B, due to a tendency of the wire to slip off the bone 198 during twisting. This was also a challenge for group C and is a direct result of reliance 199 on the soft tissue for fragment stabilisation. This may explain some of the variability in 200 the load at failure results for these techniques. Group B was found to have lower level 201 of variation which may be a consequence of more consistent implant placement. K-202 wire placement in group D was very challenging due to the small size of the patella. In 203 groups A, B and C, apposition of the articular surface was easier although the 204 reduction tended to be less stable. Stability was much improved following suture repair 205 of the retinaculae, as reported in humans (18). In groups A, B and C, the degree of 206 wire tightening was critical for accurate apposition of the fragments. Over tightening 207 led to opening of the fracture gap on the articular surface, insufficient tightening would 208 209 result in rapid loss of reduction when loaded. To ensure methodological consistency, the techniques were performed on multiple limbs prior to the measured experiments. 210

We defined failure as fracture opening of greater than 3mm. In humans, patellar fracture gap of greater than 2-3mm is considered as an indication for surgical intervention (15, 16). Use of 3mm as definition of failure was considered reasonable 214 given recent recommendations to manage cases with minimal displacement 215 conservatively (6) and this value has been used in human studies (26).

Currently, there is little clinical evidence supporting any patellar repair technique in 216 cats. In the largest report on repair of patellar fractures in cats (3) repair with pin and 217 tension band failed in 12 of 14 of cases that were followed up. Five cases were 218 repaired with circumferential wire and in all cases fragment distraction was observed 219 on follow-up radiographs. In a separate report circumferential wiring of a patellar 220 fracture in a kitten documented healing of the fracture (5). Only one reported use of a 221 222 figure eight wire has been published to the author's knowledge (2). A potential concern with the combined technique is irritation caused by the wire knots, a common 223 224 complication in humans (15).

This study had a number of limitations. Little historical information was available for 225 the cadavers used. It was therefore not possible to definitively verify the absence of 226 diseases (e.g. renal disease) that could influence results. There was some difficulty 227 in measurement of the fracture gap by video assessment due to movement of the soft 228 tissues overlying the patellar fragments. Other studies (10, 18, 20) have utilised 229 extensiometer gauges fixed with pins to directly measure opening at the fracture gap. 230 The small size of the patella fragments in this study precluded such an approach. 231 Additionally, video assessment meant that only the dorsal surface could be visualised. 232 Previous studies have found that fracture gap opening varied according to stifle angle 233 (10, 18). In this study we elected to test the stifle at a static standing angle, enabling 234 assessment of the fracture gap by video data capture and allowing both cyclic loading 235 and test to failure experiments to be performed sequentially. Video data capture would 236 not have been possible with a dynamic system since the angle of the patella with 237 respect to the camera would change affecting gap measurements. Maximum 238 disruptive forces on the patella have been shown to occur at around 45 degrees of 239 stifle flexion in humans, which is equivalent to the 135 degree standing angle used in 240 this study (17). 241

In conclusion, our study found that a combination of circumferential and figure eight wires had the overall best performance of the techniques. Further work is required to determine whether this technique is suitable for use in clinical cases. Figure 1. Patellar fracture repair methods: A – Circumferential wire, B – Figure eight
wire, C – Combined circumferential and figure eight wires, D –Pin and tension band
wire.

Figure 2. Jig utilised for testing feline patellar fracture repairs: The limb was clamped with the stifle held at 135°. The femur was secured by an intramedullary pin held in place with dental cement. During cyclic loading the muscle was clamped and needles passed through the clamp. In test to failure experiments the clamp was cooled in liquid nitrogen prior to securing the muscle.

Figure 3. Maximum fracture gap opening at peak load under cyclic loading (mean ± SD). Groups C and D had significantly lower fracture gap opening than group A (p .012 and p .002 respectively) but were not significantly different from group B. The difference between group A and B approached statistical significance (p .07).

Figure 4. Load at failure in test to failure experiments (mean \pm SD). Group C had significantly higher force at failure when compared to all other techniques (p <.05). There was no difference between the other groups.

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