Introduction

External skeletal fixators (ESF) are commonly used for fracture stabilisation in veterinary orthopaedics and are available in a variety of configurations. They can be used as either sole fixation or adjunct stabilisation for a wide variety of conditions making them a versatile tool. Numerous reported advantages of ESF include, ease of placement, accessibility for open wound management, ease of implant removal and reduced cost of placement with minimal requirement for specialised orthopaedic equipment[1-4]. While Improvements with surgical technique and equipment have led to a decreasing frequency of complications over the last three decades, fixator associated complication rates remain high[5], particularly implant failure and pin-tract infection[3, 6-11]. Development of Fixator associated complication's in dogs has previously been up to 100% in some studies[9,12].

Although numerous published studies of specific ESF configurations at defined anatomic locations have been reported, to the authors' knowledge, a comprehensive multiregional review of fixator complications has not been undertaken. The aim of this study was to review postoperative complications directly attributable to the ESF apparatus in dogs, specifically implant infection, implant failure and bone fracture, and to identify factors associated with their development.

Materials and methods

Medical records of dogs with an ESF placed between January 2007 and March 2014 at the Queen Mother Hospital for Animals were reviewed. The information in the records was reviewed in full for the entire period until the fixator was removed. The following information was gathered for each patient: signalment, ESF configuration, anatomical region, fixator associated complications and fracture type (open or closed). Patients were omitted if complete records were not available. Fixator configuration was determined from clinical records and radiographs, and categorised into four groups: linear, free-form, hybrid and circular. Specific ESF features also assessed included presence of a tied-in intramedullary pin, transarticular frame, A-frame configuration and the use of epoxy putty or clamp. Each ESF was assigned to one of nine anatomical regions (Figure 1). If the fixator involved more than one region, they were classified according to the region of injury requiring stabilisation. Fixator associated complication's recorded by the case clinician were identified from the medical records and were divided into four categories: **1)** Superficial pin-tract infection , including cases with associated pin loosening, **2)** Deep pin-tract infection, including any cases with associated pin loosening, **3)** fractures and **4)** implant failure; defined as any complication associated with the frame without concurrent infection, including loosening, breakage or bending of pins, breakage of connecting bars or clamp failure, and implant migration. Superficial pin-tract infection was diagnosed by presence of one or more of the following: **(a)** purulent discharge (with or without positive bacterial culture); **(b)** a positive culture result, or; **(c)** at least one sign of infection (pain or tenderness, localized swelling, redness or heat), or a positive response to antimicrobial therapy[13]. Deep pin-tract infections were diagnosed when the previously mentioned criteria were met and radiographic evidence of osteomyelitis or bone sequestrum was seen.

Commercially available statistical software was used to perform all statistical analyses [a]. Data were assessed for normality using the Shapiro-Wilk Test. Categorical variables were analysed using Chi-square or Fisher's exact test as appropriate. For analysis of regional association with complication development and type, regions with less than six cases were excluded from analysis. Analysis of associations between age, weight and development of complications; fracture type (open or closed) and time of fixator associated complication were assessed using the Mann-Whitney U test. The Kruskal-Wallis test was used to identify associations between patient age, weight and type of complications; and associations between sex, ESF configuration, with fixator associated complication development and the time of fixator complication. Relationships between age, weight and time of complication were assessed by Spearman's rank correlation. A $P<0.05$ was considered significant.

Results

Review of the medical records from the specified period identified 119 consecutive dogs in which an ESF had been applied. From these cases, 22 were excluded due incomplete medical records. Therefore, a total of 97 dog met the inclusion criteria. Age on presentation ranged from two months to 13 years (median two years). Body weight ranged from 2.1kg to 50.8kg (median 18.5 kg). Forty-five dogs were female (23 neutered) and 52 were male (23 neutered). Forty-one breeds of dog were represented, the most common being mongrels (n=20) followed by Labrador (n = 11) then Greyhound, (n=6). Of the 97 dogs, 67 had closed fractures and 30 open fractures. Overall the most common region of placement was the radius and ulna 20/97, as shown in Figure 1. The majority of ESFs were linear in 79/97 of dogs, of which 36 were type I, 42 type II and 1 was type III. The remaining fixators were free form in 12, circular in 4, and hybrid in 2 dogs. The majority of constructs used the IMEX SK clamp system[b] 81/97 with the remaining 16 using epoxy putty. Detailed ESF configuration results are summarised in Table 1. Of the 36 transarticular frames, two involved the radius and ulna, eight the manus and 13 the pes. All fixators involving the tarsus and stifle were transarticular. All transarticular fixators were non-articulating fixed angle.

Complications

Fixator associated complication’s occurred in 67/97 of dogs which had an ESF placed. Three dogs had two distinct complication’s over time; these were treated as separate complications giving 70 distinct complications. The time to diagnosis of complications ranged from 1 to 28 weeks postoperatively (median 5 weeks). Figure 2 shows the frequency of complications that developed; the most common being superficial pin-tract infection occurring in 38/97 dogs, followed by implant failure (17/97). Of these 38 dogs, 30 were radiographed to rule out deep pin-tract infection. Complications occurred in all nine anatomical regions, summarised in Table 2. Excluding regions with less than six dogs, region of placement was significantly associated with fixator associated complication development (p=0.005). The highest complication rates were recorded in the tarsus, humerus, manus, and pes as summarised in Table 2. The lowest complication rates were in the tibia, and the maxilla and mandible. However, region was not significantly associated with the type of complication that developed (p=0.086). Regional distribution of complication types is shown in Figure 3 with superficial pin-tract infection the most common complication in four regions, including the femur 2/2, humerus 6/9, radius and ulna 11/20, and the pes 9/17. Implant failure was the most common complication in the tarsus 5/10. Deep pin-tract infection was the most frequent complication in the tibia 3/17, manus 4/9 and stifle 1/3. Bone fracture occurred in only 1 dog with a fixator applied to the manus. This transarticular circular fixator had wires placed in the distal 1/3 of the radius leading to a fracture in the distal radius at the proximal wire tract when the dog jumped from a height. The wire occupied 28% of the bone diameter.

Age was significantly associated with the incidence (p=0.029) not the type (p=0.805) of complication that developed. The median age of dogs that developed a complication was 3 years (range four months to 11 years) and those without a complication was 1 year (range three months to 13 years). No significant association between breed, sex, weight, fracture type (open or closed) and the incidence or type of fixator associated complication was identified. Similarly, there was no association between ESF type and the incidence (p=0.121) or type (p=0.108) of complication.

Of the frame features outlined in Table 1, only the transarticular ESF design was associated with an increased incidence of fixator complications however not the type of complication. The remaining features shown in the table were not significantly associated with the incidence or type of complication that developed. Thirty-six fixators were transarticular of which 29 suffered a complication in comparison to 38/61 frames with no transarticular component. Anatomical region was the only factor significantly associated with time of complication diagnosis (p=0.01). The shortest median time to diagnosis was in the femur at two weeks, followed closely by the pes with a median of two and a half weeks and longest was the crus at 10 weeks. The three dogs that suffered two separate complications had transarticular frames two at the pes crossing the tarso-metatarsal and intertarsal joints and one at the tarsus crossing the tarsocrural joint. All three had both a superficial pin-tract infection and an implant failure that occurred separately.

Discussion

The most common type of ESF used was the linear ESF, of which the type I and II arrangements predominated. Radius and ulna fractures were the most common location for ESF placement, which is unsurprising as the radius and ulna are reported to be the most commonly affected region of fracture in the dog[14]. The predominance of fixator use at this location also relates to the frequency of open fractures, the relative paucity of soft tissue and the ability to construct bilateral or biplaner frames[4, 5, 8, 11, 15].

The overall fixator associated complication rate in this study was high at 69% (67/97 dogs). Previously reported complication rates in canine populations are highly variable ranging from 5% to 100%[1,8,11,12,16,17]. The vast majority of complications were superficial pin-tract infection followed by implant failure. While the complication rate in this study is comparable to previously reported canine complication rates, it is higher than those previously reported in cats ranging from 26%-50%[6,18]. It therefore appears that dogs may be more likely to develop complications than cats, and this is something the authors' have noted anecdotally. Region of ESF placement was significantly associated with complication development, however not the type of complication that developed (Figure 3).

Pin-tract infection remains one of the most significant complications of external fixation, compromising otherwise successful treatment. Infection can lead to increased patient morbidity, increased treatment costs and client frustration[13]. Superficial pint tract infection was recorded in 38/97 dogs, this is similar to previously reported superficial pin-tract infection rates in dogs ranging from 13% to 58%[9, 15, 19]. Pin-tract infections are thought to occur when soft tissue penetration allows bacterial contamination of the skin to pin interface, leading to superficial pin-tract infection, which can progress to deep pin-tract infection, with associated bone lysis, pin loosening and osteomyelitis[10, 20, 21]. Additionally, implant allow biofilm formation allowing bacteria to evade the host immune response and antimicrobial therapy[22, 23]. Studies of the canine humerus and femur and have shown an absence of clear, safe corridors for pin placement due to the complex regional anatomy, and only limited safe corridors in the radius[24, 25]. This concurs with the results of this study showing superficial pin-tract infection as the most common complication in these regions. Interference with tendons and musculature in these regions may lead to additional discomfort, joint stiffness and decrease use of the limb, all of which may predispose patients to increased complications due to tissue morbidity and patient interference. While the overall level of complications and superficial pin-tract infections remain comparable to other canine studies direct comparison is fraught due to differences in study population, case definitions and study power lead to discrepancies when comparing study's[13]. Pin-tract infection and their prevention remain a difficult area to research due to the multifactorial nature of surgical site infection. Various strategies of pin site care have been proposed in humans, however a recent

Cochrane review suggested there was insufficient evidence to identify a strategy of pin site care that minimises infection rates[26]..Other reported risk factors for small animal surgical site infection included gender, concurrent endocrinopathies, increased bodyweight, duration of anaesthesia and surgical hypotension[27-29]. Importantly, it has been shown that the risk of developing a surgical site infections in dogs following implant placement was 5.6 times that of dogs with no surgical implants[29]. In this study however, when assessing complications, no association with body weight, or gender was found, although anaesthesia duration data was not available. Despite the high frequency of pin-tract infections, ESF implants are readily removed and minor short term morbidity associated with superficial pin-tract infections often resolves following antimicrobial administration and adequate pin care or implant removal[7,17,20].

In our population complications were less likely in younger patients. Animal models of bone healing in rats showed that, six week old rats regained normal bone biomechanics at four weeks after fracture compared with one year old rats requiring more than six months[30]. The speed of fracture healing will doubtless impact on the both duration of fixator placement and the degree load sharing, which will affect loads and duration of loading upon the implants.

The manus and pes suffered from high fixator complication rates with deep and superficial pin-tract infections predominating respectively. It has been reported that pin-tracts of fixators used to stabilise the small bones of the metacarpus and metatarsus are particularly problematic with two out of three dogs in one study developing osteomyelitis[31,32]. Similarly, the present study found that deep pin-tract infections were the most common complication to occur in the manus. Deep pin-tract infections were also common in the tibia; the limited soft tissue coverage over the medial aspect of the canine and feline tibiae make them particularly prone to complications with fracture healing due to the poor extraosseous blood supply and reduced intramedullary blood supply in the early stages following fracture[33,34]. Interestingly, in an experimental model of canine pin-tract infection, the infective agent in 88% of medullary canal cultures was also cultured from the skin[35]. Given the limited soft tissue envelope in these regions and reduced vascularity it would seem logical that superficial infection could readily progress to involve bone due to the close proximity of the bone to surface of the skin-pin interface.

Implant failure occurred in 17/97 dogs and was common in the tarsus (Figure 3). The tarsus has previously been shown as a common region for the development of fixator complications[9, 31], however reported tarsal fixator complication rates are variable between 15% and 74%[9, 36]. In our definition, tarsal ESFs were transarticular, spanning the tarsocrural joint, and indeed transarticular configurations are an independent risk for complications development. Clearly, overloaded implants, either due to patient factors or inappropriate implant choice are mechanically vulnerable, being subject to significant transarticular bending forces as they cross the flexed tarsocrural joint[11, 19, 20]. Additionally relatively small pins placed in the metatarsal bones, further increase the mechanical vulnerability. Reassuringly iatrogenic bone fracture was uncommon in this study, occurring in only one dog. A case series of 11 dogs and cats found that this complication usually had contributing factors including multiple injuries, the presence of empty drill holes and inappropriate postoperative exercise restriction[37].

A key feature of the ESF is its flexibility in design, and there are numerous frame configurations, implant types, sizes and materials to choose from[38, 39]. The only ESF feature associated with an increased complications was the presence of a transarticular frame, which may inevitably relate to the biomechanical requirements of a transarticular frame. Complications have previously been shown to be more common when more complex ESF frames are used[6, 11], however in this study no significant difference was seen between type I, II and III linear ESFs. This was surprising as there was an expectation that increased frame complexity would be associated with increased complications, due to greater soft tissue disturbance from increase pin penetration[3, 10].

Several factors not evaluated in our study must be taken into consideration when discussing fixator complications. The first is the method of pin insertion which influences the critical region of the fixator: the pin-bone interface. It is well documented that inappropriate insertion technique can lead to excessive heat generation resulting in thermal osteonecrosis and premature pin loosening[40, 41], particularly when bone is heated above 50°C for 60 seconds[42]. Canine models have shown that high speed pin insertion produces significantly higher bone temperatures and therefore slow speed insertion is recommended (150rpm or less)[3, 40, 41, 43]. Insufficient axial force when drilling bone can also significantly increase cortical bone temperatures and time above 50°C[44]. Pre-drilling a pilot hole for pin placement has been shown to increase pin pull out strength by 13.5% and reduce cortical microstructural damage leading to bone resorption and premature loosening [45]. The common recommendation in veterinary medicine is a drill bit 10% smaller than the pin diameter[43]. Unfortunately, this information was not available to this retrospective study, however these principles are typically adhered to in this centre. Another approach to maximise the pin-bone interface is to use threaded pins[3, 40]. Threaded pins have increased pin-bone contact area and increase resistance to pull-out which may significantly affect pin loosening and complication development. Finally, pin size and number has an influence the pin-bone interface. A minimum of two pins should be placed per bone segment with the majority of authors recommending three to four pins per segment[3, 37, 40].The conventional pin size recommendation is between 20% and 30% of bone diameter[40,10, 37]. Pin size is a balance between using a pin that is large enough to provide sufficient stiffness but small enough avoid leaving a critical size defect following removal[37, 40] . We should note here that even when all guidelines are followed correctly a degree of complications are expected due to the nature of a transcutaneous implants.

This study has some limitations, particularly being retrospective in nature, with multiple surgeons contributing cases, creating variation in case management and selection. Detailed evaluation of the initial injury, exact surgical techniques employed and the pin type used was not possible..The small sample size is some regions such as the stifle and femur must also be taken into consideration when interpreting regional results and may lead to overestimation of regional complication rates. Due to the referral nature of the caseload and lack of specific long term follow up under-reporting of reporting of minor complications may also have occurred. Overall it is also important to acknowledge that fixator complication development is multifactorial and a single causative factor is not always clear as multiple independent factors will interact and result in complications. The only way to evaluate all factors fully would be to perform a large prospective comparative study. Nonetheless, this represents a large overview of complications relating to external fixators and is informative to the surgeon.

On balance, ESFs complications are very common in the dog, however particular consideration should be given prior to their usage in certain locations, including the radius and ulna, humerus and femur, which are prone to pin-tract infections. Mechanical failure was not common except when used for transarticular tarsal stabilisation and bone fracture was extremely rare. This study could not show an effect of fracture configuration, open or closed nature, or frame design on the development of complications.

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