Outcomes, complications and risk factors following fluoroscopically guided transcondylar screw placement for humeral intracondylar fissure

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OBJECTIVES: To describe the surgical technique and complications for fluoroscopically guided transcondylar screw placement for humeral intracondylar fissure in dogs.

MATERIALS AND METHODS: A retrospective review was undertaken of cases from two hospitals where identical surgical technique was employed. Factors were analysed for any association with postoperative complications.

RESULTS: Sixty-two dogs (82 elbows) were reviewed for which the postoperative complication rate was 45%; a total of 15% of cases required revision surgery. Complications were more likely in cases operated on earlier in the case series and with increasing dog bodyweight. Both increasing surgical time and being a neutered female were protective against postoperative complications.

CLINICAL SIGNIFICANCE: Fluoroscopically guided transcondylar screw placement for humeral intracondylar fissure is associated with a high postoperative complication rate (45%) with 15% of cases requiring revision surgery.

INTRODUCTION

Humeral intracondylar fissure (HIF) can lead to persistent lameness, fracture with minimal trauma or can be detected incidentally. Incidental fissures are often identified when diagnostic imaging is performed on cases with contralateral humeral condylar fracture (Marcellin-Little et al. 1994, Butterworth & Innes 2001, Moores & Moores 2017). The condition has been described as an incomplete ossification of the humeral condyle (IOHC) (Marcellin-Little et al. 1994) but case reports have also documented natural progression of HIF in adult dogs with the progression of partial to complete fissures (Witte et al. 2010) and de novo fissure formation (Farrell et al. 2011). For dogs presenting with a persistent forelimb lameness and an associated HIF, treatment has been described using a transcondylar screw or a combination of a transcondylar screw and autogenous bone graft (Butterworth & Innes 2001, Fitzpatrick et al. 2009, Moores et al. 2014, Easter et al. 2020, Walton et al. 2020). The accuracy of transcondylar screw placement can be improved with the use of an aiming device, a custom printed patient-specific drill guide or intraoperative fluoroscopy (Grand 2017, McCarthy et al. 2019, Pardo et al. 2019, Easter et al. 2020). Complications associated with transcondylar screw placement for HIF are common and range from 15 to 69% with the most commonly reported complications including seroma and infection (Hattersley et al. 2011, Moores et al. 2014, Chase et al. 2019, McCarthy et al. 2019, Walton et al. 2020).

The aim of this study was to report the surgical technique, as well as the complications following fluoroscopically guided transcondylar screw placement for treatment of HIF. A number of factors were analysed to determine if they were associated with postoperative complications.
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MATERIALS AND METHODS

Animals
Ethical approval for the study was granted by the University of Bristol ethical review committee (VIN/20/015). Medical records at two veterinary referral hospitals in the United Kingdom, who practiced identical surgical techniques, were retrieved for placement of transcondylar screws for management of HIF between July 2012 and March 2019. The end date for case collection was chosen to allow a minimum follow up of 1 year after surgery. Medical records were searched in March 2020 by a single operator by searching for keywords within attached reports (Word, Microsoft) that were archived within a veterinary practice management software (Rx Works, Covetrus). Keywords searched within the text of these documents were: “hif,” “humeral intercondylar,” “humeral intracondylar,” “incomplete ossification,” “intercondylar screw,” “intracondylar screw,” “IOHC” and “transcondylar screw.” All records were manually reviewed by the same single operator and any elbow joint that had a transcondylar screw placed as part of a humeral condylar fracture repair was excluded. Data retrieved included patient identification number, date of surgery, age, breed, gender, weight, primary surgeon, veterinary hospital, reason for screw placement, computed tomography (CT) findings, surgical approach, implants, anaesthetic details, postoperative antibiotic use and 8-week follow-up findings. A complete fissure was defined as a hypoattenuating defect extending from the articular surface of the humerus to the supratrochlear foramen. A partial fissure was defined as a hypoattenuating defect that did not completely span the proximo-distal depth of the humeral condyle (Carrera et al. 2008). The presence or absence of medial coronoid process disease (MCPD) was determined based on a previous description of CT findings in Springer Spaniels (Moores et al. 2012).

Imaging
All cases had CT examination of both elbows due to investigation of either unilateral humeral condylar fracture or unilateral or bilateral forelimb lameness. Images were acquired using Siemens Emotion™ 16 slice fifth generation MSCT scanners. For each elbow, data were collected using a helical acquisition with a slice thickness of 0.6 mm, a pitch of 0.8 and a 1 s tube rotation time. For each elbow, a set kVp of 130 and variable mA were used. Scans were performed using a 59 in. field of view and a slice thickness of 0.6 mm, a pitch of 0.8 and a 1 s tube rotation time. All images were viewed using a window level of 600 and a sharpening algorithm (U91 s ultrasharp) to optimise spatial resolution. All images were viewed using a window level of 600 and a window width of 3000 Hounsfield units. Dogs were sedated for CT with a combination of intravenous (IV) dexmedetomidine (Dexdomitor, Zoetis) (5 to 10 μg/kg) and methadone (Comfortan, Dechra) (0.2 to 0.3 mg/kg) or butorphanol (Torbugesic, Zoetis) (0.2 to 0.3 mg/kg).

Anaesthesia
Dogs were anaesthetised with a combination of medications at the discretion of the attending specialist anaesthetist. This included a combination of methadone (0.2 to 0.3 mg/kg IV), dexmedetomidine (3 to 10 μg/kg IV) or acepromazine (ACP Injection, Elanco) (0.01 to 0.03 mg/kg IV). Anaesthesia was induced with either propofol (Propoflo Plus, Zoetis) or alfaxalone (Alfaxan, Jurox) given to effect and maintained with either isoflurane (Isoflurane-Vet 100%, Boehringer Ingelheim Animal Health) or sevoflurane (SevoFlo 100%, Zoetis). Propylactic antibiotics in the form of ceftiofur oxime (Zinacef, GlaxoSmithKline) (20 mg/kg IV) were given at least 30 minutes before the start of surgery and repeated every 90 minutes until skin closure.

Surgery
Following the diagnosis of a HIF (either unilateral or bilateral, partial or complete) and with written informed consent from the owner, dogs were anaesthetised, routinely prepared for aseptic surgery and transferred to the operating room (Fig 1). Dogs were positioned in dorsal recumbency with either one or both forelimbs hung from a ceiling chain, secured using multiple sterile towel clamps and wrapped with sterile bandage. Sterile covers were applied to the intraoperative fluoroscopy unit (Phillips BV Pulsera mobile C-arm) and a mediolateral and cranio-caudal view was acquired of the humeral condyle in preparation for surgery. A 1 to 2 cm medial or lateral skin incision was made, depending on surgeon preference, over the humeral epicondyle until the epicondyle was visualised and mini gelpi retractors were used, at the surgeon’s discretion, to retract the skin and soft tissues. A 1.6 mm Kirschner wire was inserted into the condyle to a depth of between 3 and 10 mm at the estimated ideal location for transcondylar screw insertion (DeCamp 2015) using a Colibri II handpiece (DePuy Synthes). Orthogonal fluoroscopic views of the humeral condyle were repeated and the Kirschner wire position and angle was adjusted as required until optimal placement was achieved. The Kirschner wire was then advanced across the humeral condyle using the Colibri II handpiece until it was just palpable on the opposite side without penetrating the skin. Frequent saline lavage was used for cooling during Kirschner wire advancement. Orthogonal fluoroscopic views of the humeral condyle were repeated to confirm optimal Kirschner wire placement. For a 4.5 mm cortical transcondylar screw a 3.2 mm cannulated drill bit (DePuy Synthes) was threaded over the 1.6 mm Kirschner wire and used to enlarge the hole over the Kirschner wire. This drill bit was used in short bursts with constant saline lavage and was withdrawn for both cleaning and lavage to cool the drill bit after every 2 to 3 seconds of use. For a 3.5 mm cortical transcondylar screw the 1.6 mm Kirschner wire was removed and the hole was enlarged with a standard 2.5 mm drill bit in a similar manner (the hole was drilled in this way as a 2.5 mm cannulated drill bit with 1.6 mm cannulation could not be sourced). For 5.5 mm cortical transcondylar screws, the 3.2 mm cannulated drill hole was enlarged with a 4.0 mm drill bit using the same short burst technique. For placement of a 4.5 mm shaft screw (Veterinary Instrumentation), previous recommendations were followed (Moores et al. 2014) using a combination of preoperative CT measurements, intraoperative fluoroscopy and drill stops (Veterinary Instrumentation). For all implants, large pointed reduction forceps were placed...
Humeral transcondylar screw

across the condyle and an appropriately sized cortical thread tap was used before transcondylar screw placement. Orthogonal views of the humeral condyle were repeated aiming for a screw length with one to two screw threads circumferentially exiting the opposite cortex. The surgical site was flushed with saline before routine closure of the antebrachial fascia with absorbable suture material (Monocryl, Ethicon) and either skin sutures (Ethilon, Ethicon) or intradermal sutures (Monocryl, Ethicon) were placed in the skin. Postoperative orthogonal radiographs were taken in all cases and no postoperative bandage material was applied except for an absorbent adhesive dressing (Prima-pore, Smith&Nephew) which was applied and maintained for 24 hours postoperatively in all cases.

Postoperative management
All cases received postoperative analgesia including methadone (0.2 to 0.3 mg/kg IV every 4 hours) or buprenorphine (0.02 mg/kg IV every 6 hours) as required and a non-steroidal anti-inflammatory (meloxicam 0.1 to 0.2 mg/kg IV or carprofen 4 mg/kg IV). A course of postoperative antibiotics (cefalexin 15 to 20 mg/kg PO for 5 to 10 days) was prescribed depending on surgeon preference. Cases were discharged from the hospital once they were comfortable and weight bearing on the operated limb, which was usually the following day, and owners were instructed to limit their dogs to short lead exercise only for the next 4 to 6 weeks.

Follow-up assessment
Definitions of complications were based on previously published criteria (Cook et al. 2010). In summary, a catastrophic complication is a complication or associated morbidity that causes permanent unacceptable function, is directly related to death, or is a cause of euthanasia. A major complication is split into two categories. Type 1 major; requires surgical treatment to resolve (e.g. implant failure or persistent infection) or type 2 major; requires medical treatment to resolve (e.g. surgical site infection). A minor complication is a complication that does not require medical or surgical treatment to resolve (e.g. seroma). A surgical site infection was recorded if any of the following criteria were identified: purulent drainage from the surgical site, organisms isolated with bacterial culture from an aseptically collected sample of fluid, tissue or an implant, pain and lameness that improves with antibiotics following cytological suspicion of infection when no organisms identified (Weese 2008). A seroma was recorded if a fluid-filled swelling was identified at the surgical site without any evidence of heat, pain, discharge or worsening lameness.

Perioperative data (0 to 3 months) was collected from clinical records up to discharge from the hospital and from clinical records at the 6 to 8 week postoperative assessment. This postoperative assessment was occasionally a telephone conversation with the owner if no complications were identified by the owner. If complications were encountered, such as a seroma, suspected surgical site infection or persistent lameness, appropriate investigations were performed, such as X-rays, joint aspirates and/or bacterial culture and sensitivity. Long-term follow up was collected by telephone conversation with owners at the time of data collection. Owners were asked a standard set of questions (Appendix S1); if any further surgery had been performed, whether they were aware of any signs consistent with a seroma or surgical site infection in the postoperative period, whether any lameness had improved following surgery and whether the dog was lame at the time of follow up. This lameness was subjectively graded as mild, moderate or severe by the owner, as previously described for a study on the same topic (Hattersley et al. 2011).
Statistical analysis
The outcome of interest for each elbow was the presence or absence of any postoperative complication following placement of a transcondylar screw. Individual types or classifications of complications were not included as an outcome of interest due to the low number of occurrences for statistical analysis. For dogs that had bilateral surgery, both the dog and the elbow of interest were not independent variables and so a multilevel logistic regression analysis was performed to take this into account. Elbows were considered a level 1 variable and dogs were considered level 2 variables. Data were analysed using MLwiN Version 3.01 (Centre for Multilevel Modelling, University of Bristol, Bristol, UK). Variables were iteratively tested within a multilevel model including chronological order of index surgery (ordinal), primary surgeon (categorical), sex and neutered status (male, male entire, female, female entire, categorical), bodyweight (kg, continuous), surgery time (minutes, continuous), implant type (3.5 cortex, 4.5 cortex, 4.5 cortex plus lateral plate, 5.5 cortex, 4.5 shaft, categorical), implant area moment of inertia (AMI) normalised to bodyweight (continuous), the surgical approach (medial or lateral, binary) and the use of postoperative antibiotics (yes or no, binary). Implant AMI=πr^2/4 (where r=0.5×core diameter of the screw). Implant AMI normalised to bodyweight=Implant AMI/bodyweight (kg) and the core diameter of the screws used is as follows: 3.5 mm cortex: 2.4 mm, 4.5 mm cortex: 3.1 mm, 5.5 mm cortex: 3.8 mm, 4.5 mm shaft: 4.5 mm (Moores et al. 2014, Synthes Vet 2017). The aim was to identify the most parsimonious predictive model for any postoperative complication. Any cases where follow up was unavailable were excluded from statistical analysis.

RESULTS

Medical records
Keyword searches identified 911 documents for review. All records were manually reviewed for eligibility and the majority of these documents were duplicates of the same case with multiple clinical records or cases receiving transcondylar screws for management of humeral condylar fracture. Following individual review 62 dogs were identified that met the inclusion criteria.

Signalment
Sixty-two dogs were operated on between July 2012 and March 2019 with 20 of these dogs having bilateral transcondylar screw placement either in a single anaesthetic (12) or with staged surgeries (eight) equating to 82 screws placed in 70 procedures during the study period. Forty-one dogs were male (14 male neutered) and 21 were female (14 female neutered). Dog breeds were 54 spaniels (40 Springer spaniels, nine Cocker spaniels and five Spaniel crosses), five Labrador retrievers, two cross breeds and not recorded in eight. Fifteen dogs (24%) were presented for treatment of a contralateral forelimb fracture. This was a bicondylar humeral fracture in three dogs and fracture to the lateral portion of the humeral condyle in 11 dogs. One dog presented due to a contralateral fractured proximal phalanx.

Surgery
Of the 82 elbows undergoing surgery, 69 had a transcondylar screw placed from medial to lateral and 13 had a transcondylar screw placed from lateral to medial. Included within this data there were four dogs that received a medial to lateral screw in one elbow and a lateral to medial screw in the contralateral elbow, either as a single surgery (n=3) or staged surgery (n=1). There were a total of 13 bilateral surgeries under the same anaesthetic: nine were operated on at a separate veterinary referral hospital. Dogs were managed by five different surgeons, with either an ECVS surgery diploma (n=4) or RCVS orthopaedic diploma (n=1).

Presenting complaint
Forty-seven dogs (76%) were presented for investigation of a persistent forelimb lameness. This was deemed a unilateral lameness in 42 dogs and a bilateral lameness in five dogs. The lameness was graded as mild in 27 dogs, moderate in five, severe in seven and not recorded in eight. Fifteen dogs (24%) were presented for treatment of a contralateral forelimb fracture. This was a bicondylar humeral fracture in three dogs and fracture to the lateral portion of the humeral condyle in 11 dogs. One dog presented due to a contralateral fractured proximal phalanx.

Imaging
Thirty-two dogs (52%) were diagnosed with unilateral HIF on presentation (33 elbows). One of these cases presented 2 years following the initial diagnosis of a unilateral HIF for contralateral lameness and was subsequently diagnosed with a newly identified HIF in the contralateral elbow. This finding was despite a previous CT of both elbows consistent with a unilateral HIF. Thirty dogs (48%) were diagnosed with bilateral HIF (60 elbows), of which 11 dogs received a unilateral transcondylar screw and the remaining 19 dogs received bilateral transcondylar screws (38 elbows). In total there were 52 right and 41 left HIF, of which 65 were complete fissures and 28 were partial fissures. Throughout the study period and within this data set, there were three cases with clear evidence of progression from partial fissures to complete fissures, as previously described (Witte et al. 2010). For the data analysis they have been described as complete fissures.

Of the 47 dogs presenting for investigation of a forelimb lameness, 30 dogs (64%) were diagnosed with MCPD with concurrent HIF and 14 dogs had CT findings consistent with periosteal proliferation of the lateral epicondylar crest with concurrent HIF (Marcellin-Little et al. 1994). Of the 30 dogs with MCPD, 19 had unilateral MCPD and 11 had a bilateral MCPD. Of the 14 dogs with epicondylar changes, 12 had unilateral changes and two had bilateral changes.

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Fifteen dogs had additional procedures performed under the same anesthetic as transcondylar screw placement. These included the addition of a lateral plate (three), elbow arthroscopy for joint evaluation only or for medial subtotal coronoidectomy (four), proximal ulna osteotomy (seven), radial lengthening (one) or repair of a contralateral fracture of the lateral portion of the humeral condyle (two).

**Anaesthesia and postoperative care**

In addition to the anesthetic protocol described, 25 cases received a preoperative brachial plexus block with bupivacaine (MSD) (1 to 2 mg/kg) and one case received a preoperative cervical paravertebral block with bupivacaine (1 to 2 mg/kg). The median anesthetic and surgical time for cases receiving a transcondylar screw (i.e. excluding additional procedures on the contralateral limb) was 160 minutes of anesthesia time (range 80 to 260) and 65 minutes of surgical time (range 15 to 200). These times included the three cases where a lateral plate was also applied following transcondylar screw placement as removal of these cases did not change the median or range of anaesthetic or surgical time. In addition to the perioperative antibiotics already described, 30 of the 70 procedures were given postoperative cephalixin for between 5 and 10 days (Rilexine, Virbac) (15 to 25 mg/kg) at the discretion of the primary surgeon.

**Follow-up**

Short-term follow up (3 to 6 months) was available for 68 of the 82 elbows (83%) and long-term follow up was available for 64 of the 82 elbows (78%). Overall, median follow up time was 641 days (range 0 to 2481). Of all the cases where long-term follow-up was available the median follow-up time was 774 days (range 395 to 2481).

**Complications**

Intraoperative complications are described as a percentage of the total number of procedures (n=70) and postoperative complications are described as a percentage of the total number of elbows operated on (n=82). All complications are summarised below (Tables 1 and 2). There were four different intraoperative complications (6%) which included: one intra-articular screw placed (range 83 to 125 days). Of all the cases where long-term follow-up was available the median follow-up time was 774 days (range 395 to 2481).

In addition to the materials and methods, 16 major complications (20%) and 20 minor complications (24%). The catastrophic complication was a case where a 4.5 mm cortical screw clinically loosened on two separate occasions. It was replaced once but on the second occasion the owner decided to euthanise the dog due to repeat problems with the screw.

**Multilevel logistic regression**

All variables in the materials and methods were iteratively tested within a multilevel model to identify the most parsimonious predictive model for any postoperative complication.

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**Table 1. Summary of postoperative complications organised by implant type and classified according to Cook et al. 2010**

| Implant type      | All complications | Catastrophic | Major (Type 1) | Major (Type 2) | Minor |
|-------------------|-------------------|--------------|----------------|----------------|-------|
| 3.5 cortex (n=12) | 6                 | 0            | 1              | 0              | 5     |
| 4.5 cortex (n=59) | 26                | 1            | 10             | 4              | 11    |
| 5.5 cortex (n=4)  | 2                 | 0            | 0              | 0              | 2     |
| 4.5 shaft (n=4)   | 3                 | 0            | 0              | 1              | 2     |
| lateral plate (n=3)| 0               | 0            | 0              | 0              | 0     |
| All implants (n=82)| 37 (45%)         | 1            | 11 (13%)       | 5 (6%)         | 20 (24%) |

The numbers provided in brackets represent the percentage complication for all surgeries (n=82)
All combinations of main effects were tested and additionally quadratic terms for all continuous variables were tested to check for linearity.

The parameter estimates of the final model are shown in Table 3. For implant type, only the 3.5 mm cortex and 4.5 mm cortex screws could be included in the model as there were less than 5 of each other implant type. The variables “Implant AMI normalised to body weight” and “primary surgeon”: were dropped from the model as there was no significant effect of these variables and their absence had little effect on the parameter estimates of the other variables.

An increasing bodyweight (OR: 1.2, 95% CI: 1.001 to 1.407, P=0.047) and surgery performed earlier in the case series (OR: 0.97, 95% CI: 0.938 to 1.000, P=0.046) were associated with an increased risk of complications. Increasing surgery time (OR: 0.98, 95% CI: 0.956 to 0.995, P=0.013) and being a neutered female (OR: 0.09, 95% CI: 0.012 to 0.644, P=0.015) were protective against developing postoperative complications. Postoperative antibiotics (OR: 0.49, 95% CI: 0.112 to 2.156, P=0.34), surgical approach (OR: 7.7, 95% CI: 0.647 to 91.286, P=0.10) and implant type (OR: 0.20, 95% CI: 0.019 to 2.045, P=0.17) had no detectable significant relationship with the risk of developing postoperative complications and the interaction of implant type and bodyweight was also tested with no significant interaction found.

Outcome

Of the 82 elbows operated on, 15 were operated on (in 15 dogs) due to the perceived risk of fracture and did not present due to lameness. Long-term follow up was available for 10 of these 15 elbows and none of these dogs demonstrated any signs of lameness according to owner telephone follow up. The remaining 67 elbows were operated on (in 47 dogs) due to a presenting unilateral or bilateral forelimb lameness. Long term follow-up was not available for 11 of the 47 dogs. All cases available for follow up reported an improvement in lameness following treatment except for one case. The case that did not report an improvement was the case that suffered an elbow luxation following proximal ulna osteotomy.

A total of 22 dogs of the 56 available for follow up, reported a continued lameness despite an improvement following treatment. Sixteen cases reported a continued mild lameness and six cases reported a continued moderate lameness.

Forty-one of the 67 elbows that were operated on due to lameness, had concurrent MCPD based on CT. Nine of these elbows received additional treatment that may have influenced their outcome including arthroscopy and medial subtural coronoidectomy (four elbows), proximal ulna osteotomy (four elbows) and radial lengthening (one elbow) leaving 32 elbows with transcondylar screws placed for HIF with concurrent MCPD in which no additional surgery was provided. Of these 32 elbows, long-term follow up was available for 28. All cases reported an improvement in lameness with transcondylar screw alone. Despite this postoperative improvement, nine elbows (32%) were reported to have persistent lameness which was either mild (seven elbows) or moderate (two elbows).

**DISCUSSION**

The primary aim of this study was to report the complications following placement of fluoroscopically guided transcondylar screws for HIF (Tables 1 and 2). The secondary aim was to identify factors that were associated with complications in these cases (Table 3). This study has identified four factors related to complications following fluoroscopic transcondylar screw placement for HIF. These included surgery being performed earlier in this case series and increasing dog bodyweight. We also found that increasing surgery time and being a neutered female dog were protective against developing a postoperative complication.

The majority of cases described in this series were young (median 3 years of age) male Springer Spaniels, in line with previous reports of HIF (Hattersley et al. 2011, Moores et al. 2014).

**Table 2. Summary of postoperative complications organised by implant type and classified according to whether revision surgery was performed or not**

| Implant type | Complications leading to further surgery | Complications not requiring further surgery |
|--------------|-----------------------------------------|-------------------------------------------|
| 3.5 cortex (n=12) | 1                                      | 5                                         |
| 4.5 cortex (n=59) | 11                                     | 15                                        |
| 5.5 cortex (n=4) | 0                                      | 2                                         |
| 4.5 shaft (n=4) | 0                                      | 3                                         |
| lateral plate (n=3) | 0                                     | 0                                         |
| All implants (n=82) | 12 (15%)                              | 25 (30%)                                  |

The numbers provided in brackets represent the percentage complication across all surgeries (n=82)

**Table 3. Parameter estimates (β) with standard error (SE) of the final multilevel binary logistic regression model, with associated p value, odds ratio (OR) and 95% confidence interval (95% CI)**

| Response | β     | SE     | OR   | Lower 95% CI | Upper 95% CI | P value |
|----------|-------|--------|------|--------------|--------------|---------|
| Constant | 1.928 | 2.277  | 0.49 | 0.112        | 2.156        | 0.39    |
| Postoperative antibiotics | –0.709 | 0.746 | 7.7  | 0.647        | 91.286       | 0.10    |
| Lateral approach | 2.039 | 1.250 | 0.20 | 0.019        | 2.045        | 0.17    |
| 4.5 mm cortex screw | –1.623 | 1.181 | 1.20 | 1.001        | 1.407        | 0.047   |
| Weight (kg) | 0.171 | 0.086 | 0.98 | 0.956        | 0.995        | 0.013   |
| Surgery time (minutes) | –0.025 | 0.010 | 0.97 | 0.938        | 1.000        | 0.046   |
| Chronological order | –0.032 | 0.016 | 0.31 | 0.058        | 1.659        | 0.17    |
| Male neutered | –1.167 | 0.845 | 0.23 | 0.017        | 3.195        | 0.27    |
| Female entire | –1.460 | 1.324 | 0.09 | 0.012        | 0.644        | 0.015   |
| Female neutered | –2.416 | 0.998 | | | | |

The primary complications following postoperative treatment were revision surgery and additional surgery. Revision surgery was performed in 22 elbows (27%) and additional surgery was required in 67% of the cases. Revision surgery was diagnosed clinically in all cases; however, only 30% of dogs that underwent revision surgery had any additional treatment. Revision surgery was predominantly performed due to failure of the initial treatment. Additional treatment was provided in 10/22 cases and included arthroscopy and medial subtural coronoidectomy (four elbows), proximal ulna osteotomy (three elbows), radial lengthening (one elbow) and lateral plate (one elbow). Nine cases required further treatment that may have influenced their outcome including arthroscopy and medial subtural coronoidectomy (four elbows), proximal ulna osteotomy (four elbows) and radial lengthening (one elbow) leaving 32 elbows with transcondylar screws placed for HIF with concurrent MCPD in which no additional surgery was provided. Of these 32 elbows, long-term follow up was available for 28. All cases reported an improvement in lameness with transcondylar screw alone. Despite this postoperative improvement, nine elbows (32%) were reported to have persistent lameness which was either mild (seven elbows) or moderate (two elbows).
As far as the authors are aware, our case series represents the largest collection of cases treated with HIF to date. All cases were managed in a similar way with all surgeries initially being performed as a single centre, but additional surgeries included from a separate centre when one of the primary surgeons moved clinics but continued using the same technique.

The technique described requires fluoroscopic imaging equipment to perform. Warm and cumbersome protective equipment is required during the procedure and use of fluoroscopy comes with the increased risk of radiation exposure (Theoharopoulos et al. 2003). The perceived advantages of this technique would be expected to include minimal soft tissue dissection and accurate implant placement, although accuracy was not assessed with our study methodology. It should be clear from the materials and methods (Fig 1) that implant placement can be checked using a small K-wire before drilling a transcondylar bone tunnel.

One of the factors that was associated with postoperative complications was having surgery earlier in this case series (Table 3). This finding could be due to a refinement in operative technique or experience developed by individuals with time. We were unable to model individual surgeons case numbers and their interactions due to the limited number of cases in the series and the number of surgeons involved (n=5). Propofol has previously been reported to increase the risk of infection following orthopaedic procedures (Heldmann et al. 1999) but there was no temporal change in induction agent use with time in this study. We also considered whether there was a temporal change in implant type with time, which was found not to be the case. We were only able to model the 3.5 mm cortex and 4.5 mm cortex screws as there were less than 5 of each other implant type present in the case series. We also found no temporal change in the placement of 3.5 or 4.5 mm cortex screws with time.

An increasing surgery time was protective against complications, a finding that is counter intuitive as an increased surgical time has previously been associated with complications in orthopaedic studies (Beal et al. 2000, Eguster et al. 2004). This could reflect the speed at which the transcondylar tunnel is drilled. The authors have noted that it is imperative to employ frequent lavage of the drill bit when drilling to minimise heat necrosis of often sclerotic condylar bone and employ a pulsatile approach of advancing the drill bit and drilling for a short period followed by removal of the drill bit and saline lavage to cool before repeating. Rushing through this step, reducing surgical time, could predispose to a higher risk of complications.

We also found that increasing bodyweight was associated with an increased risk of postoperative complications (Table 3). This finding has also been reported in a similar publication on this topic (Hattersley et al. 2011) and in previous studies following orthopaedic procedures (Arthurs & Langley-Hobbs 2006, Casale & McCarthy 2009). This could be due to relatively smaller implants being placed in heavier dogs but the relative AMI for heavier dogs would only decrease by a very small amount and we found no interaction between implant type and bodyweight in the multilevel model and when implant AMI was normalised to bodyweight there was no association with the risk of postoperative complications.

We did not identify any implant failures or complications requiring revision surgery with the larger implants in this case series (5.5 cortex, 4.5 shaft, 4.5 cortex plus a lateral plate). This finding is only based on 11 implants and further work is needed to determine if larger implants would reduce the risk of postoperative complications requiring further surgery. We were unable to model any variables against implant failure alone as there were only five implant failures in this group of cases.

Being a neutered female dog was found to be protective for developing a postoperative complication. A previous publication has found male entire dogs to be at increased risk of postoperative infection (Fitzpatrick & Solano 2010). Our findings support this previous finding as male entire was the baseline category against which all other variables in this category were compared (e.g. male neutered, female entire, female neutered) and therefore represents a risk factor for developing a postoperative complication. Eleven of the 37 complications were due to infection in this study. We do not know of a clinical explanation for sex status influencing postoperative complications or postoperative infections and no explanation was discussed in the previous publication with this finding (Fitzpatrick & Solano 2010).

One previous abstract has suggested an overall complication rate of 10% when transcondylar screws are placed from medial to lateral as positional screws in HIF cases (Clarke et al. 2012). We analysed screw direction placement as a variable but did not find any difference in complication rates with screws placed from lateral to medial compared with 69 elbows with screws placed from medial to lateral. There were only 13 elbows with screws placed from lateral to medial compared with 69 elbows with screws placed from medial to lateral and so identifying no difference in complication rate may simply reflect a type II error. Further suitably powered studies would be needed to determine if screw direction influences the postoperative complication rate.

One previous retrospective study on transcondylar screw placement for HIF (Hattersley et al. 2011) found a lower postoperative complication rate when lag screws were placed across the humeral condyle for management of HIF, as opposed to positional screws. We did not observe a similar finding but we have only reported four elbows where the screw was placed in a lag fashion and these were all due to the placement of a 4.5 mm shaft screw. All remaining screws were placed as positional screws in this case series.

The majority of cases in this series (76%) presented with a forelimb lameness which was deemed to be due to the HIF. We found that 64% of cases with a HIF also had concurrent MCPD. In order to make observations as to whether surgical treatment of concurrent MCPD was necessary in these cases, we identified 28 cases from this series with HIF and MCPD that received no surgical treatment of their MCPD and were available for long-term follow up. The owners of all of these cases reported an improvement in lameness following transcondylar screw placement alone, a similar finding in cases without concurrent MCPD in this series. Nine of these 28 cases (32%) still had a persistent lame- ness, despite the improvement, which is of unknown significance but could have been due to the concurrent MCPD. Based on these findings and the previous report demonstrating that 50% of case series...
Spriger Spaniels have MCPD seen on CT (Moore et al. 2012) we commonly pursue surgical treatment of HIF alone in cases found to have both HIF and adjunctive MCPD with the option of future surgical intervention for MCPD, if lameness persists.

This study was retrospective in nature and comes with inherent limitations. In order to avoid under-reporting of complications we only included cases in which surgery had been performed a minimum of 1 year before data collection. We relied on medical records and owner telephone follow up to identify long-term complications in these cases. The assessment of long-term outcome was limited to owner telephone follow-up which has inherent limitations. We failed to achieve long term follow up (defined as greater than 1 year) for 18 elbows and so the reported complication rates described should be interpreted based on the inherent limitations of this follow-up data. One of the major complications identified in this study, implant failure, occurred a median of 273 days following surgery with one instance of implant failure occurring 4 years following surgery.

In summary, fluoroscopic placement of transcondylar screws for management of HIF was associated with a postoperative complication rate of 45% with 15% of all cases requiring revision surgery. Complications were more likely in cases operated on earlier in the case series and with increasing dog bodyweight. Both increasing surgical time and being a neutered female were protective against postoperative complications.

Conflict of interest

None of the authors of this article has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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Supporting Information

The following supporting information is available for this article: Appendix S1. Follow up questionnaire.

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