Amelioration of caudal thoracic syringohydromyelia following surgical management of an adjacent arachnoid cyst

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A nine-year-old male, neutered, pug was presented for investigation of progressive ambulatory para-paresis and pelvic limb ataxia of three months’ duration. Magnetic resonance imaging was suggestive of caudal thoracic syringohydromyelia with an adjacent intradural arachnoid cyst. The cyst was marsupialised following dorsal laminectomy. Neurological status had improved 10 weeks following surgery when repeat magnetic resonance imaging revealed reduced spinal cord compression both as a result of resolution of the cyst and reduction in size of the syringohydromyelia. At 17 months following surgery, the dog showed further improvements in neurological status, exhibiting mild pelvic limb ataxia and proprioceptive deficits. Improved cerebrospinal fluid flow following surgery may have played a role in the improvement in both conditions. The presence of syringohydromyelia in this context does not preclude a favourable clinical outcome following surgical management.

INTRODUCTION

Syringohydromyelia has been widely reported in dogs in association with Chiari-like malformation, but has also been described less commonly in more caudal locations in association with other pathologies including arachnoid cysts (Galloway and others 1999, Skeen and others 2003, Jurina and Grevel 2004, Foss and Berry 2009). Although clinical improvements in dogs with Chiari-like malformation often follow medical and surgical interventions (Rusbridge and others 2006), associated reductions in syrinx dimensions have not been reported (Skerrit and Hughes 1998, Vermeeersch and others 2004, Rusbridge 2007). The term syringomyelia refers to a syrinx located within the parenchyma of the spinal cord, whilst hydromyelia describes dilation of the central canal (Milhorat and others 1995, Rusbridge and others 2006). As such definitive syrinx classification is challenging premortem, the terms syringomyelia or syringohydromyelia have been widely used irrespective of precise syrinx location (Rusbridge and others 2000, Cappello and Rusbridge 2007).

Spinal arachnoid cysts have been reported as a cause of spinal cord compression with increasing frequency in the veterinary literature, with almost 100 cases described since the first report in 1968 (Gage and others 1968, Parker and Smith 1974, Parker and others 1983, Bentley and others 1991, Dyce and others 1991, McKee and Renwick 1994, Hardie and others 1996, Bagley and others 1997, Cambridge and others 1997, Shamir and others 1997, Ness 1998, Frykman 1999, Galloway and others 1999, Vignoli and others 1999, Webb 1999, Hashizume 2000, Rylander and others 2002, Gnirs and others 2003, Skeen and others 2003, Jurina and Grevel 2004, Chen and others 2005, Sessums and Ducote 2006, Goncalves and others 2008, Foss and Berry 2009). They are also reported as a relatively uncommon cause of myelopathy in humans (Lee and Cho 2001). Despite this there remains considerable confusion in both the human and veterinary literature as to the precise aetiology and structure of spinal arachnoid cysts, with the term being used indiscriminately to describe a number of different fluid-filled structures within the vertebral canal. Indeed, the term “cyst” is itself confusing because these structures generally do not comprise closed, epithelial lined cavities (Nabors and others 1988, Hamburger and others 1998). Although “pseudocyst” has been proposed as an alternative (Jurina and Grevel 2004), in this report the term “cyst” will be used to maintain consistency with the existing human and veterinary literature.

This report describes a reduction in syringohydromyelia dimensions following surgical management of an adjacent spinal intradural arachnoid cyst (SIAC) in a pug.
CASE REPORT

A nine-year-old male, neutered, pug weighing 7.2 kg was presented for investigation of progressive pelvic limb incoordination and weakness of three months’ duration. On clinical examination, the dog exhibited moderate ambulatory paraparesis and hindlimb ataxia. Neurological examination of the cranial nerves and thoracic limbs was unremarkable. The cutaneous trunci reflex was absent caudal to the 13th rib bilaterally but there was no evidence of spinal hyperaesthesia. Pelvic limb segmental spinal reflexes were normal although severe bilateral symmetrical proprioceptive deficits were present. The perineal reflex was intact. These findings were suggestive of a T3-L3 myelopathy; differential diagnoses at this stage included intervertebral disc disease, neoplasia, discospondylitis, inflammatory central nervous system (CNS) disease and arachnoid cyst.

The results of haematology and serum biochemistry were within reference ranges. Following premedication with 0.02 mg/kg acepromazine (IM; ACP Injection, Novartis Animal Health) and 0.2 mg/kg methadone hydrochloride (IM; Physeptone, Martin-dale Pharmaceuticals), general anaesthesia was induced with 2 mg/kg propofol (Rapinovet, Schering-Plough) and maintained with isofluorane in oxygen. Magnetic resonance imaging (MRI) of the thoracic and lumbar spine was performed (GE Signa HDe 1.5 T MRI scanner). Sagittal and transverse T1- and T2-weighted sequences were acquired as well as a dorsal 3D FIESTA sequence. Slice thickness was 2 mm (sagittal and 3D FIESTA) and 1.5 mm (transverse).

MRI images are presented in Fig 1. There was a focal, extramedullary, intradural accumulation of cerebrospinal fluid (CSF) located dorsal to the spinal cord over the caudal aspect of the T11 vertebral body which was causing moderate to marked cord compression. Craniocaudal, dorsoventral and laterolateral measurements were 4.1, 1.8 and 3.1 mm, respectively; differential diagnoses included arachnoid cyst, synovial cyst, epidermoid cyst and cystic neoplasia. An area of T2-weighted hyperintensity,
consistent with syringohydromyelia, extended from the level of the T8-T9 intervertebral disc space to just beyond the site of cord compression, with the greatest dilation being at the level of the T10-T11 intervertebral disc space. Craniocaudal length was 25 mm and maximum diameter was 2.5 mm. Small-volume intervertebral disc protrusions were evident at T11-T12 and T12-T13. At T11-12 this was resulting in loss of the ventral subarachnoid space although this was preserved dorsally. There was minimal right ventral extradural cord compression at T11-T12 associated with the protruded disc material.

A dorsal laminectomy of T11 was performed using a high-speed bur [Surgairtome II; Hall (Linvatec)] following a standard approach (Toombs and Waters 2003, Piermattei and Johnson 2004). Caudally the laminectomy was similar to a Funkquist Type B laminectomy with preservation of the cranial articular processes of T12 and the majority of the caudal articular processes of T11 (Toombs and Waters 2003); cranially the articular processes were preserved. The surface of the dura was grossly normal and a midline durotomy was performed with the aid of loupes (Keeler Standard Loupes 2.5x; Keeler Ltd.). Incision through a single, thickened layer of tissue released a large volume of CSF, apparently under some pressure. The spinal cord appeared depressed especially in the midline. A biopsy of the meningeal layer was placed in 10% buffered formalin and submitted for histopathology. The margins of the durotomy were sutured loosely to the laminar periosteum and facet joint capsule bilaterally with 0.7 m polydioxanone (PDS II; Ethicon) before routine closure. Recovery from surgery was unremarkable with unchanged neurological status the following day.

Histopathology findings indicated the meningeal layer to be composed of dense fibrous connective tissue. There was no evidence of inflammatory infiltration. The surgical and histopathological findings were consistent with a dilation of the subarachnoid space bounded ventrally by pia mater and dorsally by fibrosed arachnoid and dural layers.

Neurological examination four weeks following surgery revealed mild ambulatory paraparesis and ataxia. The cutaneous trunci reflex was abnormal as previously described; severe pelvic limb proprioceptive deficits also remained. Neurological examination after 10 weeks revealed persistent mild ambulatory paraparesis and ataxia although this had subjectively improved. A reduced cutaneous trunci reflex of normal extent had returned bilaterally, and mild pelvic limb proprioceptive deficits were present. Repeat MRI was recommended to quantify the degree of persistent spinal cord compression associated with the arachnoid cyst and to exclude progression of the disc protrusions. MRI was performed under general anaesthesia using the previously described protocols. The dorsally located CSF accumulation over the caudal aspect of the T11 vertebral body was no longer visible (Fig 2). There was diffuse T2-weighted hyperintensity affecting the majority of the cord at that level; differential diagnoses included glial scarring, parenchymal oedema and myelitis. The area of T2-weighted hyperintensity consistent with syringohydromyelia had decreased significantly in size to 6 mm × 1.2 mm × 1.2 mm and was located at the level of the body of T11. There was no gross progression of disc protrusion, and no further treatment was recommended.

At the time of writing (17 months following surgery) the dog’s neurological status has remained stable with ongoing mild bilateral pelvic limb ataxia.

**DISCUSSION**

The incidence of concurrent syringohydromyelia and arachnoid cysts in dogs is unknown. MRI findings have been reported in only 21 cases of arachnoid cysts in dogs (Galloway and others 1999, Rylander and others 2002, Gnirs and others 2003, Skeen...
and others 2003, Jurina and Grevel 2004, Chen and others 2005, Sessums and Ducote 2006, Goncalves and others 2008, Foss and Berry 2009), four of which had syringohydromyelia (Galloway and others 1999, Skeen and others 2003, Jurina and Grevel 2004, Foss and Berry 2009). In humans partial occlusion of the subarachnoid space causing obstruction of CSF flow is considered a key factor in the aetiopathogenesis of syringohydromyelia (Batzdorf 2005, Mauer and others 2008). This may occur at the cranio-cervical junction (most commonly in association with Chiari malformations) (Levine 2004) but also more caudally, secondary to arachnoid cysts, adhesive arachnoiditis, neoplasia, spinal malformations and intervertebral disc protrusions (Klekamp 2002, Batzdorf 2005, Holly and Batzdorf 2006). In dogs Chiari-like malformation is the most widely described cranio-cervical junction lesion associated with syringohydromyelia, although brainstem tumours have also been reported (da Costa and others 2004, Jung and others 2006). More caudally, syringohydromyelia has been described in association with spinal dysraphism (Furneaux and others 1973), vertebral malformation (Chauvet and others 1996) and intervertebral disc disease (McGrath 1965), as well as arachnoid cysts.

Numerous theories have sought to describe a common aetiology-pathogenesis for syringohydromyelia in these diverse circumstances, and detailed reviews covering the human (Klekamp 2002) and veterinary (Rushbridge and others 2006) literature are available. Although the precise mechanisms remain unclear, there is recent evidence to suggest that altered CSF flow may affect the drainage of parenchymal extracellular fluid (ECF) with subsequent oedema and syringmyelia (Klekamp 2002), a process promoted by parenchymal injury due to transmedullary transmission of CSF pulse pressure waves (Rushbridge and others 2006). A prior theory, the hydrodynamic hypothesis, proposed that subarachnoid CSF flow obstruction elevated intra-ventricular pressure and forced CSF into the central canal, resulting in hydromyelia (Gardner and Goodall 1950). In humans, however, greater pressures within syrinxes than the adjacent subarachnoid space (Heiss and others 1999) are inconsistent with syrinx pressurisation from the fourth ventricle, and rostral central canal stenosis is present in most humans over 30 years of age (Brodbelt and Stoodley 2007). The situation in dogs and cats may not be entirely analogous because the central canal may remain patent (Fitzgerald 1961, Rushbridge and others 2006); hydromyelia occurred in up to 69% of dogs (Hall and others 1980, Yamada and others 1996, Chuma and others 1997) and all cats (Becker and others 1972, Rascher and others 1987) following experimental subarachnoid space occlusion, and occurs in combination with hydrocephalus with severe fourth ventricle outflow obstruction in dogs (Itoh and others 1996, Kirberger and others 1997) and cats (Okada and others 2009). In addition, high syrinx pressures have not been measured in clinical cases in dogs or cats.

In humans, spinal arachnoid cysts have been described in extradural, dural and intradural locations. Spinal extradural arachnoid cysts are reported relatively frequently in humans and represent accumulations of CSF within a thin-walled sac within the epidural space (Nabors and others 1988). This sac is a diverticulum of the arachnoid mater and thus communicates with the subarachnoid space via a pedicle which penetrates a congenital or acquired dural defect (Nabors and others 1988, Liu and others 2007). Spinal dural cysts are rare lesions resulting from developmental duplication or splitting of an area of dura mater with accumulation of CSF (Hamburger and others 1998). Neither spinal dural cysts, nor extradural arachnoid cysts have been reported in animals.

Spinal intradural arachnoid cysts (SIACs) in humans result from abnormalities of the arachnoid mater and subarachnoid space including the arachnoid trabeculae and may be acquired or congenital (Pradilla and Jallo 2007). Congenital SIACs in humans are rare (Wang and others 2003) and may represent CSF accumulation within the septum posticum (Perret and others 1962) or pathologically distributed arachnoid trabeculae (Agnoi and others 1982). These typically discrete structures may be true cysts with a cuboidal cell lining and amenable to complete resection (Mohindra and others 2010). Acquired SIACs in humans occur in association with adhesive arachnoiditis (Petridis and others 2010) which may be secondary to spinal surgery, myelography, infection, subarachnoid haemorrhage and spinal trauma (Lee and Cho 2001, Wang and others 2003). The resultant adhesions affecting the subarachnoid space may be discrete or extensive (Batzdorf 2005), take the form of a dense focal web (Mallucci and others 1997, Paramore 2000), or incorporate discrete pockets of CSF (Kazan and others 1999, Tumialan and others 2005). MRI has been used to measure CSF flow in patients with arachnoid adhesions (Mauer and others 2008, Gotschalk and others 2010); sagittal cardiac-gated phase-contrast CSF flow studies have revealed reduced CSF flow at the level of surgically confirmed arachnoid adhesions. Postoperative imaging revealed normalisation of CSF flow after adhesion resection, as well as reduced dimensions of associated syringomyelia in the majority of patients (Mauer and others 2008). Increased CSF hydrostatic pressure rostral to an area of arachnoid adhesions may result in subarachnoid space dilation and cord compression (Paramore 2000), a concept supported by fluid dynamics modelling (Bilston and others 2006). Such CSF accumulations are erroneously described as cysts, contributing to the confusion surrounding the nomenclature of these lesions.

Parallels exist between descriptions of SIACs in the veterinary and human literature. A congenital SIAC has never been specifically described in a dog, although cases in puppies (Ness 1998) and related individuals (Ness 1998, Frykman 1999) have been reported. There are four reports of the removal of entire cysts (Bentley and others 1991, Frykman 1999, Skeen and others 2003, Foss and Berry 2009), a finding more consistent with congenital rather than acquired SIACs. Although detailed descriptions of lesions are limited in the veterinary literature, the majority of those available are consistent with acquired SIACs. The most detailed anatomic description of a canine SIAC (Dyce and others 1991) describes a dilated subarachnoid space beneath a thickened dura, open cranially but sealed caudally by pia-arachnoid adhesions, findings almost identical to those described by Paramore in humans (Paramore 2000). Caudal or circumferential adhesions have been described in four further reports (Gage and others 1968, Frykman 1999, Galloway and others 1999, Gnirs and others 2003), and there are 19 specific descriptions of subarachnoid space dilation (Dyce and others 1991, McKee and Renwick 1994, Ness 1998,
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Gnirs and others 2003). It has been suggested that the predisposition of high cervical and thoracolumbar sites to SIAC formation is linked to their relatively high mobility leading to chronic meningeal microtrauma and adhesive arachnoiditis (Gnirs and others 2003, Skeen and others 2003). SIACs have also been reported in association with caudal cervical spondylomyelopathy (Skeen and others 2003), vertebral deformity (Bagley and others 1997) and disc protrusion (Chen and others 2005), conditions potentially associated with increased mobility. SIACs in dogs following spinal surgery (Galloway and others 1999) and fracture (Skeen and others 2003) may also have been the result of arachnoid adhesions.

The link between acquired adhesive arachnoiditis, reduced CSF flow and syringohydromyelia formation is less well established in dogs. This association was considered in a recent case report of syringohydromyelia where mild disc protrusion (affecting the subarachnoid space only, as in this case) was proposed as a possible cause of arachnoid adhesions and reduced CSF flow (Cagle 2010). An attempt to quantify CSF flow using MRI at the site of an SIAC has been made in one dog (Gnirs and others 2003). CSF flow at the site of the SIAC (analysed by the 2D Fourier transform steady-state free precession technique) was found to be normal. Prior myelography had however revealed an abrupt end to the contrast medium column, a finding inconsistent with normal subarachnoid fluid flow. Further MRI studies, possibly utilising a sagittal cardiac-gated phase-contrast technique, may shed light on this apparent discrepancy.

The recognition of partial subarachnoid space obstruction as a key factor in the aetio-pathogenesis of syringohydromyelia has led to a recent trend in human surgery towards restoration of CSF flow rather than traditional shunting procedures (Mallucci and others 1997, Batzdorf 2005). In the context of SIACs, microsurgical removal of obstructions to CSF flow is considered the treatment of choice in humans (Mauer and others 2011). SIAC resolution and reduction in syrinx dimensions have been reported with this approach (Holly and Batzdorf 2006, Mauer and others 2008, 2011). The surgical management of SIACs in dogs has focussed on decompression of the spinal cord rather than restoration of CSF flow, with the additional aim of prevention of recurrence by dural fenestration or marsupialisation. The prognosis for short-term improvement or resolution of neurologic signs is favourable, probably as a result of acute cord decompression. Deterioration at greater than one year after surgery has been reported in four dogs (Frykman 1999, Skeen and others 2003), possibly as a result of fibrosis of the dural defect (McKee and Renwick 1994). Follow-up MRI has not been previously reported following surgical management of concurrent syringohydromyelia and SIAC, but has been described following foramen magnum decompression for Chiari-like malformation where syrinx size was unchanged at follow-up up to 3-8 years (Vermeersch and others 2004, Rusbridge 2007). Two reports have described reduction in size of a cervical syrinx following treatment of a compressive extramedullary lesion at the foramen magnum (da Costa and others 2004, Takagi and others 2005). In both cases MRI revealed concurrent ventriculomegaly, and the syrinx probably represented communicating hydromyelia, a situation documented by postmortem examination in dogs with brainstem meningioma (Jung and others 2006) and epidermoid cyst (MacKillop and others 2006).

In the current case, these concepts may support a role for reduced CSF flow in the aetio-pathogenesis of both the subarachnoid space dilation/SIAC and the syringohydromyelia. It is proposed that arachnoid adhesions may have occurred secondary to the T11-12 disc protrusion, although an unrelated cause is possible. Resultant obstruction of CSF flow could have caused rostral subarachnoid space dilation and syringohydromyelia, the latter either through altered ECF dynamics or as a result of communicating hydromyelia. The authors suggest that improvement of CSF flow following surgery (albeit through marsupialisation rather than restoration of subarachnoid space patency) contributed to the resolution of the subarachnoid space dilation/SIAC and reduction in syrinx size.

To the authors’ knowledge, reduction in syrinx dimensions and concurrent clinical improvement following surgical management of an SIAC in a dog has not previously been reported. This case also demonstrates that the presence of syringohydromyelia and mild disc protrusion in this context do not preclude a favourable clinical outcome following surgical management. Although technically demanding procedures such as microsurgical dissection of arachnoid adhesions and duraplasty are probably unnecessary in dogs, consideration of subarachnoid space patency and CSF flow may prove a useful component of a rational surgical approach to these conditions and lead to improved long-term surgical outcomes.

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.

References


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A comparison of complication rates and clinical outcome between tibial plateau levelling osteotomy and a modified cranial closing wedge osteotomy for treatment of cranial cruciate ligament disease in dogs

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Abstract

OBJECTIVE: To report complication rates and clinical outcomes following tibial plateau levelling osteotomy (TPLO) and a modified cranial closing wedge osteotomy (mCCWO) for treatment of cranial cruciate ligament disease in dogs.

STUDY DESIGN: Prospective cohort study.

SAMPLE POPULATION: Dogs weighing between 20kg and 60kg with unilateral cranial cruciate ligament disease treated by either TPLO (n=97) or mCCWO (n=74).

METHODS: Clinical and radiographic assessments including lameness score, morphometric measurements and tibial plateau angle (TPA) were made prior to surgery and at eight weeks following either TPLO or mCCWO. Long term outcome assessment by owner questionnaire or interview was undertaken at a minimum of six months post-operatively.

RESULTS: Significant differences in lameness scores between groups were not identified at short or long term follow-up. Major complication and re-operation rates did not differ significantly between groups (TPLO 7.2% and 6.1%, mCCWO 9.5% and 5.4%). Median post-operative TPA did not differ significantly between groups (TPLO group 5.5°; mCCWO group 6.5°). At >6 months owner assessed lameness, disability, quality of life and satisfaction were not different between groups and were good in 90-97% of cases.

CONCLUSIONS: TPLO and mCCWO are associated with similar complication rates and clinical outcomes when performed by surgeons experienced with the surgical techniques.

CLINICAL RELEVANCE: Both techniques can be considered equally appropriate for the treatment of cranial cruciate ligament disease in dogs weighing between 20kg and 60kg.

Introduction

Cranial cruciate ligament (CCL) disease is one of the more common causes of pelvic limb lameness in dogs. Although the precise aetiopathogenesis of this condition remains unclear, the resultant stifle instability has become accepted as an important pathophysiological mechanism leading to the development of progressive osteoarthritis and, in some cases, meniscal injury. A key component of this instability was defined by Slocum and Devine as cranial tibial thrust (CTT), a cranially directed tibiofemoral shear force generated as axial compression acts on the caudally inclined tibial plateau during weight bearing. Whilst definitive descriptions of the forces acting across the normal and cranial cruciate deficient canine stifle remain elusive, most surgical approaches aim to counteract CTT either through static or dynamic stabilisation during the stance phase of gait.

Cranial closing wedge osteotomy (CCWO) was the first dynamic stabilisation technique described for the treatment of CCL disease. Post-operative tibial plateau angles were not reported in the original paper, although a subsequent in vitro biomechanical study demonstrated elimination of CTT following CCWO at a tibial plateau angle (TPA) of 4-6°. Slocum subsequently described a radial tibial plateau levelling osteotomy (TPLO) which also results in neutralisation of CTT at a similar TPA. Since both approaches appear capable of providing dynamic stifle stabilisation other factors must be considered when choosing between these techniques, and indeed other biomechanically appropriate surgeries. Such factors are diverse and include functional outcome, complication rates, technical difficulty, incidence and severity of unwanted effects of surgery (e.g. limb shortening), and surgeon preference.
Assessment of long term function in clinical cases is challenging\textsuperscript{11}, and in the context of TPLO and CCWO has predominantly been limited to owner assessed outcomes which do not indicate a superior outcome following either technique. Corr and Brown reported 92\% ‘good’ or ‘excellent’ outcomes with both techniques\textsuperscript{12}. Similar outcomes have been reported at rates of 86\%\textsuperscript{13} and 94\%\textsuperscript{9} following CCWO, and 94\%\textsuperscript{8} and 94.7\%\textsuperscript{14} following TPLO.

Complication rates reported following TPLO in four large retrospective cases series published between 2003 and 2006\textsuperscript{14-17} were analysed by Boudreau to give an overall complication rate of 26.3\%\textsuperscript{18}. Two large more recent retrospective studies reported lower complication rates of 9.7\% and 14.8\%\textsuperscript{4,19}. Re-operation rates have been reported at between 5\% and 9\%\textsuperscript{15,17}. Much less data is available for CCWO although relatively high complication rates of 31-36\%\textsuperscript{12,20} and re-operation rates of 12-18\%\textsuperscript{6,12,20,21} have been reported with this technique following treatment of CCL rupture in medium and large dogs.

We hypothesised that the outcomes and complication rates of TPLO and a modified CCWO (mCCWO) for the treatment of CCL disease would be similar when performed by surgeons experienced in the relevant technique, when assessed in a prospective cohort study.

Materials and Methods

Inclusion criteria, and data collection and surgical protocols were determined prior to instigation of the study in June 2009. Dogs eligible for inclusion weighed between 20kg and 60kg, were presented with naturally occurring unilateral CCL disease, and had no evidence of any other concurrent stifle pathology on physical examination and radiographic evaluation. Dogs presented for revision CCL disease surgery were excluded, as were dogs presented with any evidence of bilateral CCL disease. Consecutive cases meeting these criteria were enrolled until the termination of the study in March 2011. Cases re-presented for treatment of contralateral CCL disease within the study period, or prior to completion of long term follow up, were retrospectively excluded. During the study period two surgeons performed TPLOs, and two performed mCCWOs; within each group one surgeon was a boarded specialist and one an experienced resident. All surgeons had completed a minimum of 200 tibial plateau levelling procedures prior to the start of the study. Case allocation to a given surgeon occurred as reception staff (who were unaware of the existence of the study) arranged routine appointments with the next available surgeon.

Pre-operative evaluations

Following clinical examination, investigations including synoviocentesis, goniometry of the affected stifle\textsuperscript{22}, measurement of mid-thigh muscle circumference, and digital radiography were performed either under heavy sedation or under general anaesthesia prior to surgery. Caudocranial and mediolateral radiographs were centred on the stifle but included the tarsus\textsuperscript{22}. Projections were repeated if there was not complete superimposition of the femoral condyles on the mediolateral projection. Conventional tibial plateau angle\textsuperscript{24} was recorded and an osteophyte score attributed based on maximum osteophyte size (none, mild <1mm, moderate 1-3mm, severe >3mm). Additional data collected included duration of lameness and surgeon assessed lameness score (from 0 to 10, where 0 corresponded to no observable lameness and 10 to non-weight bearing lameness).

Surgical planning

In both the TPLO and mCCWO groups target TPA was 5\°. The planned osteotomy position was marked on a digital radiograph and measurements made in relation to bony landmarks to maximise intra-operative accuracy. To minimise translation of the tibial plateau, TPLO osteotomies were centred as near as possible to the base of the intercondylar eminence\textsuperscript{25} (Figure 1). Three millimetre blade size increments were available (between 18mm and 30mm). Rotation distance was planned according to a standard published table (New Generation Devices, Glen Rock, NJ).

MCCWOs were planned using a novel method (Figure 2). An isosceles triangle shaped wedge was positioned as proximally as possible whilst preserving sufficient bone stock for plate fixation, and remaining an adequate distance distal to the tibial tuberosity. This distance was a minimum of five millimetres for dogs under 25kg, and a minimum of 10 millimetres for heavier dogs. The planned wedge angle varied with TPA to compensate for greater tibial long axis shift associated with larger wedges\textsuperscript{26} (Table 1).

Surgical technique
Standard premedication was with acepromazine (0.01-0.03mg/kg; ACP Injection, Novartis Animal Health) and methadone hydrochloride (0.3mg/kg; Physeptone, Martindale Pharmaceuticals) by intramuscular injection. Methadone was re-administered as necessary during and following surgery. Meloxicam (0.2 mg/kg; Metacam, Boehringer Ingelheim) or carprofen (4 mg/kg; Rimadyl, Pfizer Animal Health) were administered subcutaneously at premedication. Clavulanate potentiated amoxicillin (20 mg/kg; Augmentin, Glaxo-SmithKline) was administered intravenously at induction and repeated every 90 minutes during anaesthesia.

For both TPLO and mCCWO, dogs were positioned in lateral recumbency with the affected side adjacent to the table. Following hanging limb surgical preparation, standard four quarter draping was performed prior to application of an adhesive iodine-impregnated drape which was subsequently sutured to the wound edges. A standard medial approach to the stifle and proximal tibia was made and a craniomedial sub-patellar arthrotomy performed. The integrity of the cranial cruciate ligament was assessed; rupture was recorded as partial if taut fibres were palpable, and complete when the remaining ligament was flaccid or fully ruptured. Stifle distractors were placed and the meniscus visually examined and probed with a meniscal hook (Veterinary Instrumentation, Sheffield, UK). Meniscal injuries were treated by resection of the damaged portion; meniscal release was not performed. Caudal and lateral subperiosteal elevation and placement of moistened gauze swabs was performed prior to osteotomy in all cases. A jig (Slocum Enterprises, Eugene, OR) was used for all TPLOs but not mCCWOs. TPLO osteotomies were made using an in-line oscillating saw (De Soutter, Aston Clinton, UK) with New Generation Devices TPLO blades (Glen Rock, NJ). MCCWO osteotomies were performed using a MiniDriver K220 sagittal saw; an attempt was made to preserve a small 'hinge' of intact caudomedial cortex. For TPLO, reduction was maintained using a cranially positioned K-wire placed adjacent to the patellar tendon; the K-wire was removed following plate application. For mCCWO, 0.8mm or 1mm orthopaedic wire (Veterinary Instrumentation, Sheffield, UK) was placed through 1.1mm or 1.5mm drill holes positioned cranially immediately proximal and distal to the osteotomy surfaces; the osteotomy would reduce about its caudal hinge as this was tightened. This wire was placed as a loop tightened with a single twist medially, and was not removed. Care was taken to ensure the cranioproximal drill hole was not adjacent to the insertion of the patella tendon. In all cases an appropriately sized locking TPLO plate was applied (Synthes, West Chester, PA). All proximal screws were locking screws; distal screws were either all standard cortical screws or included one or two locking screws according to surgeon preference and plate size. Routine layered closure was performed following lavage, and a sterile adhesive dressing applied for 24 hours. Surgical time and any intra-operative complications were recorded. Post-operative radiographs were assessed with respect to TPA and completeness of osteotomy reduction; the widths of any osteotomy gaps were recorded. Post-operative radiographs from the same cases illustrated pre-operatively are presented in Figure 3. Dogs were routinely discharged on the day following surgery; the presence or absence of consistent weight bearing on the operated limb was recorded.

All dogs received a five day course of either clavulanate potentiated amoxicillin (20mg/kg; Synulox, Pfizer Animal Health) or cephalexin (20mg/kg; Rilexine, Virbac Animal Health) and a four week supply of either meloxicam (0.1mg/kg PO SID; Metacam) or carprofen (2mg/kg PO BID; Rimadyl). Lead-only exercise for 10-15 minutes three times daily was advised until follow-up examination after eight weeks. Recommended physiotherapy comprised passive range of motion exercises performed by the client three times daily for the first two weeks following surgery.

Complications

Complications were recorded either following re-presentation of a patient or following notification from an owner or referring veterinary surgeon; in addition owners were questioned regarding complications at scheduled eight week re-examination and at long term follow-up.

All known major complications were investigated by the surgeon responsible for the case. Joint sepsis was diagnosed on the basis of synovial fluid neutrophilic pleocytosis and/or positive bacterial culture. Implant related infection was diagnosed when synovio-centesis was unremarkable but aspiration adjacent to the plate revealed neutrophilic pleocytosis and/or positive bacterial culture. All cases of late meniscal injury were diagnosed at arthrotomy. Implant failure was diagnosed when radiography revealed gross post-operative alteration in the orientation of the osteotomy fragments considered to be responsible for lameness.

Almost all minor complications were assessed and treated by referring vets. When available a specific diagnosis was recorded (e.g. seroma or wound self-trauma). All other reported episodes comprised non-specific wound problems such as minor peri-incisional swelling or erythema which resolved rapidly with symptomatic treatment. These cases were recorded as minor incisional complications.
Short-term follow-up

Re-examination was scheduled at eight weeks following surgery and was undertaken by the surgeon responsible for the case. Clinical examination included lameness scoring and measurement of stifle standing angle. Mid-thigh muscle circumference measurement, stifle goniometry and radiographs were obtained under heavy sedation. Radiographic assessment included TPA, implant integrity and osteotomy healing. Osteotomy healing was graded as either complete (remodelled callus at all cortices and/or osteotomy indistinct), good (active bridging callus, osteotomy mostly blurred or filled with callus), poor (some evidence of bone healing but unbridged cortices and/or osteotomy gaps), or none.

Long-term follow-up

Long-term follow-up was undertaken at a minimum of six months following surgery. All owners were sent a postal questionnaire (Appendix 1). Owners were firstly asked to list any complications and to assess the pain associated with surgery as none, mild, moderate or severe. The same choices were given for the severity of current lameness and current disability associated with the operated limb. Finally overall quality of life and owner satisfaction were rated as good, fair or poor. Non-responding owners were telephoned and the same questions asked.

Statistical analysis

Continuous data were analysed for normality by the Kolgomorov-Smirnov test. Data with normal distribution were analysed by the Student's t-test (independent data) or paired Student's t-test (continuous data). Data with a non-parametric distribution were analysed using the Mann-Whitney U test. Ordinal data was analysed with the Mann-Whitney U test (independent variables) or the Wilcoxon signed rank test (paired data). Categorical data were analysed with the Chi-squared test, or Fishers exact test if the expected frequency of data in any cells was <5. Statistical significance was set at p < 0.05, and the False Discovery Rate correction was applied to all comparisons to correct for the multiple permutation error rate. All analyses were performed using a commercially available statistical software package (Minitab for Windows, Coventry, UK).

Results

Signalment

During the study period 100 dogs met the inclusion criteria for inclusion in the TPLO group; three of these dogs were re-presented for contralateral CCL disease and were excluded leaving a total of 97 stifles (55 left, 42 right). Median age was 58 months (95% CI = 51.5, 64.5; range, 16-144 months) and median weight was 36kg (95% CI = 34, 38; range, 21-60kg). There were 50 male (37 neutered) and 47 female (39 spayed) dogs. Median duration of lameness prior to surgery was 72 days (95% CI = 55.5, 97; range, 2-365 days) and median osteophyte score was 1.5. For the mCCWO group 79 dogs met the inclusion criteria; five were excluded due to subsequent contralateral CCL disease leaving a total of 74 stifles (34 left, 40 right). Median age was 60.5 months (95% CI = 53.5, 68; range, 12-120 months) and median weight was 36.5kg (95% CI = 34.5, 38.5; range, 20-56kg). There were 38 male (32 neutered) and 36 female (35 spayed) dogs. Median duration of lameness was 67 days (95% CI = 52, 95; range, 2-365 days) and median osteophyte score was 1.5. Breeds represented on more than five occasions included (n; TPLO / CCWO); Labrador retriever (39;21/18), crossbreed (30; 13/17), rottweiler (25;13/12), golden retriever (21; 16/5), boxer (17; 10/7), dobermann (9; 6/3), German shepherd dog (9; 3/6), husky (6; 2/4) and Staffordshire bull terrier (6; 5/1). Seventeen other breeds were represented five or fewer times. There was no significant difference between TPLO and mCCWO groups with respect to side affected (P = 0.41), age (P = 0.91), weight (P = 1.00), gender (P = 1.00), neuter status (P = 0.13), duration of lameness (P = 1.00), osteophyte score (P = 0.30) and breed (comparing the common breeds listed above; P = 1.00).

Follow-up interval and availability

Short-term follow-up data was available for 70/97 TPLO cases (72%) and 57/74 mCCWO cases (77%). Median intervals to short term follow-up were 58 days (95% CI = 56.5, 60; range, 41-105 days) for the TPLO group and 56.5 days (95% CI = 54, 59.5; range, 40-96 days) for the mCCWO group. Long-term follow-up data was available for 90 TPLO cases (93%) and 69 mCCWO cases (93%). Median intervals to long term follow-up were 458.5 days (95% CI = 417, 494; range, 202-782 days) for the TPLO group and 448 days (95% CI = 407.5, 492; range, 180-731 days) for the mCCWO group.
### Surgical data

The rate of medial meniscal injury was not significantly different between groups ($P = 0.44$; TPLO group 29%, mCCWO group 38%). The rate of complete versus partial cruciate ligament rupture was not significantly different between groups ($P = 0.07$; TPLO group 71% complete, mCCWO group 86%).

Median pre-operative TPA was not significantly different between groups ($P = 1.00$; TPLO group 24.5° (95% CI = 23.5, 25; range, 15-38°), mCCWO group 24° (95% CI = 23.5, 25; range, 15-35°)). Median post-operative TPA was not significantly different between groups ($P = 1.00$; TPLO group 5.5° (95% CI = 5, 6; range, 2-13°), mCCWO group 6.5° (95% CI = 6, 7; range, 3-10°)). In both groups there was a significant increase in median TPA between surgery and short-term follow-up (TPLO group median follow-up TPA 7° (95% CI = 6, 7; range, 2-20°), $P < 0.001$; mCCWO group 8° (95% CI = 7.5, 8.5; range, 2-13°), $P < 0.001$).

Median surgical time for the TPLO group 67.5 minutes (95% CI = 67.5, 70; range, 55-100 minutes) and for the mCCWO group 73.5 minutes (95% CI = 71.5, 75; range, 54-100 minutes); these were significantly different ($P = 0.001$). Plate selection is summarised in Table 2; significantly fewer broad plates were applied in the TPLO group (21%) than the mCCWO group (42%) ($P = 0.01$). Radiographically apparent osteotomy gaps were significantly less frequent in the TPLO group (31%) than the mCCWO group (59%) ($P = 0.002$); this data is summarised in Table 3. In the mCCWO group lateral gaps were most frequent and had a median width of 1.1mm; in the TPLO group gaps were usually cranial and had a median width of 1mm.

The rate of intra-operative complications was not significantly different between groups ($P = 0.88$). In the TPLO group three such complications occurred (3%) and included fibular fracture during rotation, a hole drilled in the fibula (which subsequently fractured), and misdirection and failure to lock of a proximal screw. In the mCCWO group two intra-operative complications occurred (3%) and included misdirection and failure to lock of a proximal screw and osteotomy malreduction (with 7° tibial varus deformity). With the exception of the latter case (where long term owner assessed lameness was mild), none of these cases experienced known post-operative complications or were assessed to be lame by their owners at long-term follow-up.

The severity of owner assessed pain at the time of discharge was not significantly different between groups ($P = 0.64$); these results are summarised in Table 4.

### Lameness

Median pre-operative lameness score was 5.5/10 for both groups ($P = 0.99$). Median lameness score at short term follow-up was 1/10 for both groups ($P = 1.00$) and differed significantly from before surgery for both groups ($P < 0.001$).

At long term follow-up owner assessed scores for lameness and disability due to the affected limb did not differ significantly between groups ($P = 1.00$ and 0.88 respectively). For the TPLO group these were considered absent or mild in 95.5% (lameness) and 97.7% (disability) of cases. For the mCCWO group lameness and disability were both considered absent or mild in 92.7% of cases. Client assessed outcome scores are summarised in Table 5.

There was no significant difference between groups with respect to the frequency of consistent weight bearing on the operated limb on the day following surgery ($P = 1.00$). This was noted in 73% of TPLO cases and 75% of mCCWO cases.

### Goniometry and thigh muscle circumference

At short term follow-up there had been significant increases in stifle extension in both the TPLO and mCCWO groups ($P < 0.001$); this was associated with significantly increased stifle ROMs in both groups (Table 6). Median standing angle at short term follow-up was not significantly different between groups ($P = 0.18$; TPLO group 135° (95% CI = 135, 137.5), mCCWO group 134° (95% CI = 132.5, 135)). There was no significant difference in thigh muscle circumference between pre-operative values and those at short term follow-up in the TPLO group ($P = 0.19$) or the mCCWO group ($P = 0.43$).

### Complications

There was no significant difference between groups in the rate of major complications ($P = 1.00$) or the re-operation rate ($P = 0.72$). In the TPLO group major complications were seen in seven cases (7.2%). These
Comprised four late meniscal injuries (LMI), one of which also had joint sepsis and another of which also had grade 2/4 medial patellar luxation (MPL), one further case of joint sepsis, one confirmed implant associated infection requiring implant removal, and one implant failure. The implant failure comprised lateral osteotomy collapse with fibular fracture and resulted in 11° tibial valgus and a TPA of 20°; revision surgery was declined, and there was moderate persistent lameness. All other cases required surgical treatment, giving a re-operation rate of 6.1%. Long term owner assessed lameness was available in the following cases; LMI alone - mild (1), absent (1); LMI and MPL - mild; implant sepsis - absent. In the mCCWO group major complications were seen in seven cases (9.5%) and comprised three septic joints (all of which resolved with extended antibiotic treatment), and four late meniscal injuries (treated by debridement at arthrotomy) giving a re-operation rate of 5.4%. Long term owner assessed follow-up was available for two of the sepsis cases where lameness was absent (1) or mild (1), and all LMI cases where lameness was absent (2), mild (1) and severe (1).

There was no significant difference in the rate of reported minor complications between groups ($P = 0.41$). In the TPLO group these were reported in 16 cases (17.2%) and comprised seroma (7), minor incisional complications (5), wound self-trauma requiring re-suturing (3), and one case with moderate serosanguinous wound discharge persisting for 72 hours. In the mCCWO group minor complications were reported in eight cases (10.8%) and comprised minor incisional complications (4), wound self-trauma requiring re-suturing (3), and one case of implant associated infection which resolved with antibiotic treatment.

There was a significant difference between groups in osteotomy healing grade at short term follow-up, with the mCCWO group more advanced ($P = 0.01$) (Table 7); specific treatment of delayed union was not necessary in any case.

**Owner assessed quality of life and satisfaction**

At long term follow-up overall owner satisfaction and owner assessed overall quality of life (QOL) scores did not differ significantly between groups ($P = 1.00$).

For the TPLO group owner assessed QOL scores were available for 89/97 cases (92%); grades were as follows - good (n=81; 91%), fair (n=7; 8%), poor (n=1; 1%). In three cases QOL was influenced by other factors (neurological disease (n=2), other orthopaedic disease (n=1)). If these cases were excluded from analysis outcomes were as follows - good (n=81; 94%), fair (n=5; 6%), poor (n=0). In this group overall owner satisfaction was reported in 90/97 cases (93%); grades were as follows - good (n=81; 90%), fair (n=7; 8%), poor (n=2; 2%).

For the mCCWO group owner assessed QOL scores were available for 69/74 cases (93%); grades were as follows - good (n=62; 90%), fair (n=4; 6%), poor (n=3; 4%). In three cases QOL was influenced by other factors (other orthopaedic disease (2) and epilepsy (1)). If these cases were excluded from analysis outcomes were as follows - good (n=62; 94%), fair (n=1; 1.5%), poor (n=3; 4.5%). In this group overall owner satisfaction was reported in 69/74 cases (93%); grades were as follows - good (n=64; 93%), fair (n=2; 3%), poor (n=3; 4%).

**Discussion**

In the absence of compelling evidence favouring a specific surgical option for treatment of CCL disease the topic has remained the subject of debate and ongoing research. In recent years this has focused on TPLO and tibial tuberosity advancement, with other techniques receiving less attention. Our results indicate that outcomes and complication rates of mCCWO are similar to those following TPLO, both within the context of a prospective cohort study, and in comparison with recent large retrospective studies.$^4,19$

CCWO technique has changed very little since its original description by Slocum in 1984.$^6$ Performed as an adjunct to hamstring muscle advancement, a cranially based bone wedge was removed from the proximal third of the tibia. This wedge was asymmetric since its base was perpendicular to the long axis of the tibia, resulting in a cranial cortical ‘overhang’ following reduction with caudal cortical alignment. Where descriptions are available, subsequent in-vitro$^7,26$ and clinical$^{12}$ reports have employed a similar technique, with wedges excised around the level of the distal tibial crest.$^7,12,13,20,26$ Tibial long axis shift (TLAS) associated with distal osteotomy position and caudal cortical alignment results in under-correction of TPA unless the wedge angle is increased to at least TPA+5°.$^7$ In our study wedge geometry was modified to reduce TLAS. Firstly, the isosceles design permitted a more proximal osteotomy position (due to reduced wedge size for a given angular correction$^{29}$ and the transverse orientation of the wedge). Precise osteotomy planning relative to the tibial tuberosity further optimised proximal positioning. Secondly, optimal cranial and caudal cortical alignment is achieved, further reducing TLAS. Variable
post-operative TPA has been reported following traditional CCWO and has been cited as a disadvantage of the technique. In this study appropriate and predictable TPAs (median 6.5°; range, 3-10°) were achieved with wedge angles between TPA-5° and TPA-2° despite a wide pre-operative TPA range (15-35°). This is attributed to minimisation of the unpredictable effect of TLAS and precise pre-operative wedge planning. Additional cited disadvantages of traditional CCWO include unaesthetic craniocaudal tibial angulation and patellar baja as a result of limb shortening. Such changes are mitigated by reduced wedge size and are likely to be small; a recent investigation of a cranial neutral wedge osteotomy demonstrated tibial shorting of only 2.5mm with the traditional CCWO technique.

Inclusion criteria were designed to include medium and large breed dogs with naturally occurring cruciate disease. Dogs weighing over 60kg were excluded to maintain implant consistency between groups since the authors currently employ double plating of mCCWOs in dogs >60kg. Dogs weighing under 20kg were excluded since previous studies have shown good outcomes following CCWO; we would routinely perform mCCWO rather than TPLO in most of these cases. Similarly bilaterally affected cases were excluded to avoid the potential confounding effects of bilateral disease.

Subjective osteophyte scoring systems have been used to monitor the progression of osteoarthritis in the canine stifle. Although this approach is associated with moderate inter-observer reliability, we chose to further standardise osteophyte scoring on the basis of maximal osteophyte size (using a modification of a system used to assess the radiographic severity of canine elbow osteoarthritis). Osteophyte scores derived in this way did not vary between groups; pre-operative TPA, the number of meniscal injuries, and the frequency of partial cruciate ruptures were also equivalent between groups and did not differ widely from reported values. The rate of intra-operative complications was not significantly different between groups. Misdirection and failure to lock of a proximal screw occurred in both groups and was not noted during screw placement in either case. Although cross-threading may confer a degree of angular stability, it is probable that non-locking screw function would result. In-vitro torsional testing of a hybrid locking plate construct with one conventional and two locking screws per fragment found no difference to an all locked construct, although reduced torsional stability with only one locking screw per fragment has also been reported. In our two cases TPA was unchanged at short-term follow-up and post-operative complications were not encountered. We did not see haemorrhage from the cranial tibial artery in any case. Whilst there is evidence that caudolateral placement of swabs to protect the artery may be unnecessary during TPLO, a higher risk of vascular trauma may exist during mCCWO due to the oblique saw blade orientation necessary for caudolateral corticotomy, and swab placement is therefore prudent.

Median post-operative TPA was not significantly different between groups but was slightly further from the target of 5° in the mCCWO group (6.5°) than TPLO group (5.5°). On this basis a slight increase in wedge angle from those presented in Table 1 could be considered, although it seems improbable that this difference would be of clinical significance. Possibly of greater importance is the ability of the mCCWO technique to achieve predictable post-operative TPA values (range 3-10°). Imprecision during osteotomy execution and the unpredictable effect of TLAS may explain the observed deviation from target TPA. Post-operative TPA range following TPLO was in fact slightly wider (2-13°), although still within the range associated with good clinical outcomes in a previous study. Failure to achieve planned proximal fragment rotation was recorded in three out of four of our TPLO cases where post-operative TPA was greater than 10°. This occurred despite a pre-operative TPA of 18° in one case, and may have been associated with ankylosis of the proximal tibiofibular joint or cranial centring of the osteotomy (resulting in fibular tethering). MCCWO is apparently less susceptible to this difficulty, although osteotomy reduction can become more challenging at wedge angles >25°.

Small osteotomy gaps were commonly noted following mCCWO and most frequently affected the lateral cortex. The potential adverse biomechanical effects of a small transcortical gap were not manifest either in terms of implant failure in any case or poor osteotomy healing. This may have been due to the splinting effect of the fibula or the robust mechanical properties of the construct following locking plate application. MCCWO osteotomy gaps were usually associated with an incomplete osteotomy; on occasions when the caudomedial cortical ‘hinge’ failed complete reduction usually resulted, and could be maintained easily during plate application by the cranial wire. Small TPLO osteotomy gaps were almost always cranial and occurred in 31% of cases. These probably developed during proximodistal compression of a slightly asymmetric osteotomy (resulting from use of a non-biradial blade). Complications relating to these small cranial gaps were not encountered. Medial and lateral gaps were unusual, in contrast to a recent report where these occurred in 26% of cases.

In both groups median TPA increased by 1.5° between post-operative and short-term follow-up radiographic assessments. Previous studies have reported median TPA increases of 1.5° and 1.8° following TPLO; after CCWO a median increase of 3° has been reported. Causative factors remain uncertain, although in a recent
In humans thigh circumference has been shown to correlate with isokinetic strength42 and quadriceps muscle mass43, and has been used in both humans44 and dogs45,46 as a measure of limb use and function following cruciate surgery. In one study mean thigh circumference following TPLO was reduced after three weeks but had surpassed pre-operative levels by seven weeks46. Conversely Monk reported unchanged thigh circumference at six weeks following TPLO in dogs not receiving physiotherapy47. With only two data points per dog our results could fit either scenario, although they do demonstrate equivalence between TPLO and mCCWO groups with respect to this measure of post-operative limb function.

Following TPLO significant long term reductions in mean stifle range of motion (ROM) have been demonstrated46,48, which in some cases are associated with lameness particularly when extension is compromised48. In the shorter term however dogs receiving intensive physiotherapy following TPLO exhibit significant increases in total stifle ROM46 and stifle extension47, possibly as a result of resolution of acute stifle swelling associated with cruciate injury46. Our findings demonstrate similar increases in stifle ROM following both mCCWO and TPLO (predominantly as a result of increased extension), despite the modest nature of the physiotherapy regimen. We additionally showed that the post-operative standing angle of the stifle did not differ between groups and was approximately 135°, a similar value to that measured in normal dogs50,51. Both these findings are consistent with a kinematic study which showed increased stifle extension angles during the swing phase of gait after both TPLO and CCWO, but unchanged extension angles during the stance phase52. Thus concerns that CCWO may result in stifle hyperextension (to compensate for patella baja) with resultant gait abnormalities appear unfounded7. In fact reduction of patellar tendon angle via decreased TPA whilst stifle angle remains constant will reduce CTT53 and may be key to the ability of CCWO to dynamically stabilise the stifle; a similar mechanism has been demonstrated following TPLO54. The effect of patella baja is unknown, although did not appear to adversely affect long term outcomes in this cohort.

In humans thigh circumference has been shown to correlate with isokinetic strength42 and quadriceps muscle mass43, and has been used in both humans44 and dogs45,46 as a measure of limb use and function following cruciate surgery. In one study mean thigh circumference following TPLO was reduced after three weeks but had surpassed pre-operative levels by seven weeks46. Conversely Monk reported unchanged thigh circumference at six weeks following TPLO in dogs not receiving physiotherapy47. With only two data points per dog our results could fit either scenario, although they do demonstrate equivalence between TPLO and mCCWO groups with respect to this measure of post-operative limb function.

Long term outcome assessment following veterinary orthopaedic surgery is challenging55. Kinetic and kinematic studies provide objective measures of limb function and have been used to assess outcome after cruciate surgery46,56. Gait analysis cannot however assess broader, and clinically relevant, questions including vet and owner assessments of the overall benefit of a particular intervention11,12. Such subjective outcome measures should ideally be validated, for example by the development of a disease-specific health measurement instrument57. In common with this study, long term owner scored outcomes following TPLO have typically been assessed using combinations of unvalidated Likert scales and derivations of the Bristol Osteoarthritis in Dogs questionnaire12,14,19,58 (which has shown reliability for owner assessments of generic and disease-specific outcomes following cruciate surgery59). Gait analysis equipment was unfortunately not available for this study, and recall for long term veterinary assessment was impractical given our widely distributed referral population. Thus whilst acknowledging the limitations of our outcome assessments we feel they are comparable to previous studies and permit comparison between our mCCWO technique and TPLO both within this study and with previous reports. Higher rates of long term follow-up were achieved in this study (92-93%) compared to previous reports (69-78%)12,14,19. Our results indicated that at long term follow-up owner assessed patient quality of life and overall satisfaction following mCCWO and TPLO were both good in ≥90% cases and poor in ≤4%. Indeed, poor outcomes were frequently due to health problems unrelated to the cranial cruciate ligament disease. Equivalent 90-95% good overall owner reported outcome and / or satisfaction rates have been reported following TPLO14,19 and CCWO12. In our study owner assessed lameness at long term follow-up was mild or absent in 92.7% (mCCWO) and 95.5% (TPLO); similar rates have been previously reported following TPLO14 and CCWO13.

Comparison of complication rates between studies is hampered by inconsistent categorisation, inadequately detailed reporting, and, in many cases, low rates of long term follow-up. A recent editorial proposed categorisation of major complications as those requiring re-operation or medical treatment to resolve60. Significantly this definition includes joint sepsis which we feel is appropriate given the typical morbidity associated with this problem and the potential for suboptimal long term outcome61. We did however categorise as minor those complications considered
to be associated with minimal patient morbidity or potential for long term adverse sequelae, including self-trauma requiring resuturing, minor incisional complications and implant associated infection rapidly responsive to antibiotics. On this basis major complications occurred in 9.5% of cases following mCCWO and 7.2% of cases following TPLO. In two recent large series major complication rates following TPLO were 6.6% and 4.2%. The slightly higher major complication rates in our study may reflect the inclusion of medically managed joint sepsis cases in this category. Re-operation rates in our study were relatively low (5.4% mCCWO, 6.1% TPLO) and comparable to those reports (6.6%4, 4.2%19). With specific regard to CCWO, Corr reported re-operation in four cases (18%; 3 implant failure. 1 LM)12, whilst Kuan reported a re-operation rate of 12.3% including four cases of implant failure causing osteotomy instability and three tibial fractures20. Tibial fractures and implant failure have also been reported following CCWO at rates of 9%21 and 4%19. Major complication rate and re-operation rate following our mCCWO appear to be lower than previously reported and similar to TPLO; implant failure and tibial fracture, relatively common in previous CCWO reports, were not encountered.

Minor complication rates in our study (mCCWO 10.8%, TPLO 17.2%) are higher than those recently reported following TPLO (8.2%4 and 5.5%19). The reasons for this are unclear. With only two exceptions these cases were not re-examined by the authors creating potential for misdiagnosis and misinterpretation of the normal appearance of the healing incision. It is also probable that the prospective design of the study, and the high rates of short and long-term follow-up, resulted in a high detection rate of such episodes. Technical errors could also have been responsible, although this seems less probable given that almost all such complications were apparently associated with healing of a standard medial surgical incision.

True randomisation of cases was not possible although it is improbable that bias was introduced in this manner. A further potential source of bias was the follow-up assessment of their own cases by surgeons who were by definition aware of which procedure had been performed in that dog. It could also be argued that all four surgeons should have performed both techniques, although the approach adopted aided surgical consistency within groups. A control group was not included, although the aim of this study was to compare a novel technique with an established one, rather than to prove efficacy of either technique per se. Contralateral stifles were assessed clinically only, and it is possible that cases with very early contralateral cruciate disease which would otherwise have been excluded were missed; however it is improbable that such cases would have significantly affected overall results.

In conclusion, we found that in the treatment of dogs weighing between 20 and 60kg with naturally occurring cranial cruciate ligament disease a modified CCWO yielded predictable post-operative TPAs and similar complication rates and long term functional outcomes to TPLO. Both techniques can therefore be considered as equally appropriate for the treatment of these cases.

References


Figure 1 - Pre-operative radiograph to illustrate TPLO planning. The osteotomy is centred as close as possible to the intercondylar eminence whilst maintaining sufficient bone stock for plate application. The osteotomy diverges from the cranial tibial cortex to preserve a broadening wedge of bone supporting the tibial tuberosity, and exits the caudal tibial cortex at approximately 90°. Post-operative radiographs for this dog are presented in Figure 3.

Figure 2 - Pre-operative radiograph to illustrate mCCWO osteotomy planning. The wedge was an isosceles triangle drawn perpendicular to the cranial cortex. Distance x (between the tibial tuberosity and proximal osteotomy) was modified to preserve sufficient bone stock for plate application and an adequate distance distal to the tibial tuberosity (a minimum of five millimetres for dogs under 25kg, and 10 millimetres for heavier dogs). Post-operative radiographs for this dog are presented in Figure 3.
Figure 3 - Post-operative radiographs following mCCWO and TPLO. Mediolateral projection following mCCWO (a); note intact caudomedial cortical 'hinge' and alignment of cranial cortex. Caudocranial projection following mCCWO (b); note wire loop secured with single medial twist. Mediolateral (c) and caudocranial (d) projections following TPLO.
### Tables

<table>
<thead>
<tr>
<th>TPA</th>
<th>Wedge angle</th>
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<tr>
<td>≤20°</td>
<td>TPA - 5°</td>
</tr>
<tr>
<td>21-25°</td>
<td>TPA - 4°</td>
</tr>
<tr>
<td>26-30°</td>
<td>TPA - 3°</td>
</tr>
<tr>
<td>31-35°</td>
<td>TPA - 2°</td>
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**Table 1** - Planned wedge angles based on pre-operative tibial plateau angle (TPA)

<table>
<thead>
<tr>
<th>Synthes locking TPLO plate size</th>
<th>TPLO</th>
<th>mCCWO</th>
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<tr>
<td>2.7mm</td>
<td>2 (2.1%)</td>
<td>2 (2.7%)</td>
</tr>
<tr>
<td>3.5mm small</td>
<td>2 (2.1%)</td>
<td>3 (4.1%)</td>
</tr>
<tr>
<td>3.5mm standard</td>
<td>73 (75.3%)</td>
<td>38 (51.4%)</td>
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<tr>
<td>3.5mm broad</td>
<td>20 (20.6%)</td>
<td>31 (41.9%)</td>
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**Table 2** - Summary of Synthes locking TPLO plate selection in TPLO and mCCWO groups

<table>
<thead>
<tr>
<th>Cortex affected</th>
<th>Number</th>
<th>Median gap (mm)</th>
<th>95% CI (mm)</th>
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<tr>
<td>TPLO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>67 / 97 (69%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cranial</td>
<td>26</td>
<td>1</td>
<td>0.8, 1.25</td>
</tr>
<tr>
<td>Medial</td>
<td>1</td>
<td>1.1</td>
<td>-</td>
</tr>
<tr>
<td>Lateral</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Caudal</td>
<td>3</td>
<td>0.45</td>
<td>-</td>
</tr>
<tr>
<td>mCCWO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>30 / 74 (41%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cranial</td>
<td>5</td>
<td>0.8</td>
<td>0.5, 1.8</td>
</tr>
<tr>
<td>Medial</td>
<td>18</td>
<td>1.2</td>
<td>1, 1.45</td>
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<tr>
<td>Lateral</td>
<td>38</td>
<td>1.1</td>
<td>0.95, 1.3</td>
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<tr>
<td>Caudal</td>
<td>6</td>
<td>1.45</td>
<td>1, 1.8</td>
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**Table 3** - Location and width of radiographically apparent osteotomy gaps in TPLO and mCCWO groups. In the mCCWO group gaps could affect one cortex only (n=25) or occur concurrently at two (n=15) or three (n=4) cortices, whilst in the TPLO group multiple cortices were never affected.
### Table 4 - Owner assessed post-operative pain in TPLO and mCCWO groups

<table>
<thead>
<tr>
<th>Pain grade</th>
<th>TPLO</th>
<th>mCCWO</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pain</td>
<td>4 (4.5%)</td>
<td>6 (8.7%)</td>
</tr>
<tr>
<td>Mild</td>
<td>35 (39.3%)</td>
<td>19 (27.5%)</td>
</tr>
<tr>
<td>Moderate</td>
<td>34 (38.2%)</td>
<td>27 (39.1%)</td>
</tr>
<tr>
<td>Severe</td>
<td>16 (18%)</td>
<td>17 (24.6%)</td>
</tr>
</tbody>
</table>

### Table 5 - Long term follow-up owner assessed scores for lameness and disability

<table>
<thead>
<tr>
<th></th>
<th>Lameness</th>
<th>Disability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TPLO</td>
<td>mCCWO</td>
</tr>
<tr>
<td>None</td>
<td>62 (70.4%)</td>
<td>49 (71%)</td>
</tr>
<tr>
<td>Mild</td>
<td>22 (25%)</td>
<td>15 (21.7%)</td>
</tr>
<tr>
<td>Moderate</td>
<td>4 (4.5%)</td>
<td>4 (5.8%)</td>
</tr>
<tr>
<td>Severe</td>
<td>0</td>
<td>1 (1.4%)</td>
</tr>
</tbody>
</table>

### Table 6 - Comparative pre-operative and short-term follow-up median goniometry values (with 95% confidence intervals)

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-operative (degrees) (95% CI)</th>
<th>Short term follow-up (degrees) (95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flexion</td>
<td>37.5 (35, 38.75)</td>
<td>35 (32.5, 37.5)</td>
</tr>
<tr>
<td></td>
<td>Extension</td>
<td>147.5 (145, 150)</td>
<td>157.5 (155, 160)</td>
</tr>
<tr>
<td></td>
<td>ROM</td>
<td>110 (107.5, 112.5)</td>
<td>120 (117.5, 123.5)</td>
</tr>
<tr>
<td>TPLO</td>
<td>Flexion</td>
<td>33.5 (32, 35)</td>
<td>35.5 (33.5, 37.5)</td>
</tr>
<tr>
<td></td>
<td>Extension</td>
<td>140 (138.5, 142.5)</td>
<td>149 (146.5, 151.5)</td>
</tr>
<tr>
<td></td>
<td>ROM</td>
<td>106 (104, 109)</td>
<td>113 (110, 117)</td>
</tr>
<tr>
<td>mCCWO</td>
<td>Flexion</td>
<td>140 (138.5, 142.5)</td>
<td>149 (146.5, 151.5)</td>
</tr>
<tr>
<td></td>
<td>Extension</td>
<td>147.5 (145, 150)</td>
<td>157.5 (155, 160)</td>
</tr>
<tr>
<td></td>
<td>ROM</td>
<td>110 (107.5, 112.5)</td>
<td>120 (117.5, 123.5)</td>
</tr>
</tbody>
</table>

### Table 7 - Osteotomy healing grades at short term follow-up; healing was graded as either complete (remodelled callus all cortices and/or osteotomy indistinct), good (active bridging callus, osteotomy mostly blurred or filled with callus), poor (some evidence of bone healing but unbridged cortices and/or osteotomy gaps), or none.
Appendix 1 - Postal questionnaire sent to all owners

Owner assessed outcomes following cruciate ligament surgery

For multi-choice questions please circle the best answer. Please feel free to write any additional comments.

Dog’s Name .................................................................

Today’s Date ..............................................................

At the time of surgery

• Can you rate the severity of pain associated with the operation?

   None    Mild    Moderate    Severe

• Did your dog suffer any set-backs or complications following surgery (e.g. wound problems, suddenly worsening lameness, infections)? Please give details.

   ...........................................................................................................................................................................................................................

At the present time

• Can you rate the severity of current lameness affecting the operated limb? ***

   None    Mild    Moderate    Severe

• Can you rate the severity of current overall disability as a result of the operated limb? ***

   None    Mild    Moderate    Severe

• Can you rate your dogs current overall quality of life? ***

   Normal    Good    Fair    Poor

*** If these answers are not none / normal please indicate if the current problems are as a result of the cruciate ligament rupture / surgery or a different problem.

   ...........................................................................................................................................................................................................................

Overall Impressions

• Could you indicate your overall satisfaction with the operation and your dogs recovery?

   Good    Fair    Poor
Precision of a novel computed tomographic method for the quantification of femoral varus in the dog and an assessment of the effect of femoral malpositioning

Abstract

OBJECTIVE: To assess the precision of a novel protocol for the determination of femoral varus angle (FVA) using computed tomography (CT) in dogs, and to quantify the effect of femoral rotational and sagittal plane malpositioning on measured FVA.

STUDY DESIGN: Cross-sectional study.

SAMPLE POPULATION: Femora (n=66) from dogs which had undergone pelvic limb CT examination for patellar instability (26) or other reasons (10).

METHODS: Three observers measured the FVA of each of 66 femora on three separate occasions. Standardised orientation of a volume rendered image was achieved by superimposition of the caudal and distal aspects of the femoral condyles on a lateral projection, definition of a sagittal plane axis, and finally rotation through 90 degrees to yield a cranial projection. Intra- and inter-observer variability were estimated using the intra-class correlation coefficient. The effect of variation in rotational and sagittal plane orientation on measured FVA was subsequently quantified using six femora with FVAs between -0.4° and 19°.

RESULTS: Intra-class correlation coefficients for the three observers, indicating intra-observer variation, were 0.982, 0.937 and 0.974. The intra-class correlation coefficient of the means of the results from each observer, indicating inter-observer variation, was 0.976. Consistent linear variations in measured FVA occurred as a result of rotational malpositioning in all six tested femora, and as a result of sagittal plane malpositioning in femora with FVAs ≥7.9°.

CONCLUSIONS: The reported protocol for the measurement of FVA in dogs is repeatable and reproducible. Small variations in femoral orientation, as might be expected with conventional radiography, lead to clinically significant alterations in measured FVA.

CLINICAL RELEVANCE: The use of CT should be considered for measurement of FVA in dogs with patellar instability.

Introduction

Medial patellar luxation (MPL) is a frequent cause of lameness in small breed dogs, and is recognised with increasing frequency in a number of larger breeds. It has been recognised for some time that MPL may occur in association with a number of anatomic abnormalities affecting the entire pelvic limb. Despite the potential complexity of the aetio-pathogenesis, in most cases quadriceps mechanism malalignment can be considered to be the result of malpositioning of the tibial tuberosity (tibial torsion, rotation or malformation), a femoral deformity (torsion or frontal plane angulation), or a combination of these factors. Re-alignment of the quadriceps mechanism by tibial tuberosity transposition has been the mainstay of traditional surgical management, and has generally been associated with good outcomes. Significant reluxation and major complication rates may however result from failure to recognise femoral varus as a significant factor contributing to quadriceps mechanism malalignment.

Treatment of MPL associated with femoral varus by distal femoral osteotomy (DFO) was first described in 1935 and has recently been the subject of renewed attention. Reliable quantification of femoral varus is a prerequisite for the identification of potential DFO candidates, and several recent studies have characterised the reliability of radiographic and computed tomographic femoral varus measurements in terms of precision and accuracy. The precision of a test is a description of the variation in results yielded on repeated testing of the same sample; this is assessed by evaluation of
repeatability (intra-observer variability) and reproducibility (inter-observer variability). The accuracy of a test is a description of how close the measured value is to the true value; this requires that a 'true' value be both identifiable and measurable, thus providing an unequivocal gold standard against which new tests may be assessed. Previous studies have demonstrated reasonable precision but unacceptable accuracy when compared to a reference femoral varus angle (FVA) value determined from digital photographs of dissected femora[11,15,16].

Traditional radiographic measurement of FVA is sensitive to rotational malpositioning of the femur due to the natural procurvatum of the bone; external rotation (supination) will increase apparent varus, and vice-versa[5,16]. This difficulty has led to the development of a number of criteria for determination of appropriate femoral orientation; these include parallel orientation of the femur to the long axis of the pelvis, centring of the patella on the femur, cortical bisection of the fabellae, and visibility of the tip of the lesser trochanter[11,15-17]. Obtaining optimal projections can be frustrating, especially in countries where ionising radiation regulations preclude the use of manual positioning. In addition, positioning will be influenced by normal and / or pathological variations in the position and size of the patella, fabellae and lesser trochanter. Such effects are likely to reduce both the precision and accuracy of FVA measurement, and may partially explain the failure of earlier studies to validate these techniques. The magnitude of inaccuracy introduced by femoral malposition has not been quantified and is therefore of unknown significance with respect to surgical decision making as well as planned angular correction if DFO is performed.

We hypothesised that as a result of improved standardisation of femoral orientation, a novel CT protocol would permit precise determination of femoral varus angle in dogs. We further hypothesised that relatively small variations in femoral orientation (both with respect to rotation and inclination in the sagittal plane) would result in clinically significant alterations in measured FVA.

Materials and Methods

Clinical records were searched to identify dogs which had undergone CT examination including one or both femora at our referral hospital between October 2009 and November 2011. Exclusion criteria included incomplete imaging of the bone and the presence of pathological changes likely to invalidate measurement of femoral varus (such as neoplasia affecting relevant bony landmarks and most fractures). All other femora were included in the study.

In all cases contiguous 0.625mm slices were acquired using a 16 slice GE Brightspeed scanner; images were viewed on a workstation with screen resolution 1280 x 1024 using GE volume viewer version 3.0 software. Femoral images were prepared using a volume rendered and surface shaded preset. Using magnification, the tibia was cropped taking care to avoid inadvertent modification of the contour of the femoral condyles. The pelvis was also cropped (including the portion of the femoral head within the acetabulum) along with any other bony structures (typically the contralateral limb and tail). Each isolated femur was anonymised via assignation of a unique number and was saved in a random orientation for subsequent measurement.

In the first part of the study three boarded orthopaedic surgeons measured the FVA of each femur on three separate occasions. The order in which the femora were measured on each occasion was determined using a web-based random sequence generator[3]. A standardised protocol for FVA measurement was used (Figure 1). Using magnification, the femur was orientated to achieve superimposition of the most caudal and most distal points of the medial and lateral femoral condyles. A line was drawn connecting the most caudal points of the femoral condyles and the proximal femur (typically the lesser trochanter, but occasionally the caudal aspect of the greater trochanter). The image was rotated in the sagittal plane until this line was vertically orientated whilst maintaining condylar superimposition; the image was subsequently rotated to result in a 15° caudal inclination with respect to vertical. The image was then rotated through 90° in the transverse plane to yield a cranial view of the femur. The distance between the most distal apparent extent of the intertrochanteric fossa and the most proximal apparent extent of the intercondylar notch was measured. The proximal anatomic femoral diaphyseal axis (PAA) was defined as a line connecting the centre of the diaphysis at 50% and 70% of that distance from distally. In rare cases the more proximal point coincided with the diaphyseal flare of the lesser trochanter; when this occurred the most
proximal possible point distal to the lesser trochanter was estimated and used. The distal transcondylar axis (TCA) was defined as a line connecting the most distal points of the femoral condyles. FVA was defined as the angle between the PAA and a line perpendicular to the TCA. Magnification was used to facilitate measurement of diaphyseal width, identification of the most distal points of the femoral condyles, and placement of digital callipers for angular measurement. FVA was recorded as a positive value in cases of femoral varus and a negative value in cases of femoral valgus.

Following completion of the first part of the study a fourth boarded orthopaedic surgeon assessed the effect of femoral rotation on measured FVA. Six femora were selected with mean measured FVAs of approximately 0°, 4°, 8°, 12°, 16° and 20°. The described protocol was followed until a cranial view of each femur was obtained. Additional 2° incremental rotations were then performed between -20° (external femoral rotation; supination) and +20° (internal femoral rotation; pronation) prior to FVA measurement as described above. An experienced surgical resident subsequently assessed the effect of femoral inclination in the sagittal plane on measured FVA using the same six femora. For each femur the described protocol was used to measure FVA as femoral inclination was varied in 2° increments from zero to 34 degrees of caudal inclination.

Intra-observer and inter-observer agreement were assessed with the intraclass correlation coefficient. The correlation between continuous variables was assessed using Pearson’s correlation coefficient. Statistical significance was set at P < 0.05.

Results

66 femora from 36 dogs met the inclusion criteria and were included in the first part of the study. These included 30 paired left and right femora and six unpaired femora (three left and three right). In 23 cases the presenting problem was uni- or bilateral medial patellar luxation and in three cases lateral patellar luxation. In other cases the diagnosis was tibial deformity (3), pelvic limb soft tissue neoplasia (2), and one case each of diaphyseal femoral neoplasia, suspected Osgood-Schlatter disease, capital physeal fracture, inflammatory arthropathy and pelvic limb gait abnormality.

Mean FVAs (from nine observations) for all but one femur ranged between -0.4° and 20.3°; the remaining femur had a mean FVA of -10.5°. Intra-class correlation coefficients for each of the three observers were 0.982, 0.937 and 0.974 respectively. The intra-class correlation coefficient of the means of the results from each observer was 0.976. The difference between the smallest and greatest of the three FVA values measured by each observer for each femur was calculated; the mean values of these ranges for each observer (with standard deviations) were 1.30° +/- 0.80°, 2.37° +/- 1.40°, and 1.48° +/- 0.84°. The mean of all 198 values was 1.7° +/- 1.14°. For each observer the absolute magnitude of these ranges varied between 0° and 3.5°, 0.4° and 7.9°, and 0.3° and 3.7°. The relative frequency of ranges of increasing magnitude is shown in Figure 2; these were ≤2.9° in 174 of 198 measurements (88%), and ≤3.9° in 189 measurements (95%).

Femora selected for the second part of the study had mean FVAs (from nine observations) of -0.4°, 3.8°, 7.9°, 11.0°, 15.8°, and 19.0°; these were defined as ‘true’ FVA values. For each of these six femora measured FVA varied with rotation in an almost linear fashion between 20° of internal and 20° of external rotation (Figure 3); in each case a very high degree of correlation between these variables was noted (Table 1). Regression equations demonstrated variation of measured FVA with rotation by a factor of 0.44 to 0.51; thus regardless of true FVA, approximately one degree of error in measured FVA results from every two degrees of femoral rotational malpositioning.

Figure 4 shows the effect of increasing femoral inclination in the sagittal plane on measured FVA for each femur. For femora with true FVA values of 7.9°, 11.0°, 15.8°, and 19.0°, measured FVA varied in an almost linear fashion between zero and 34° of caudal inclination. For these femora regression equations demonstrated an increase in measured FVA of approximately one degree for every six degrees of caudal inclination, a relationship apparently unaffected by the degree of true femoral varus. For the femur with 3.8° of true varus, measured FVA was apparently unaffected by the degree of caudal inclination. For the femur with -0.4° of true varus, there was a weak inverse correlation between inclination and measured FVA. Correlation coefficients and P-values in each case are presented in Table 2.
Discussion

In the assessment of dogs with MPL, quantification of femoral varus is an important element in the selection of potential DFO candidates, a treatment which has been shown to be successful where FVA is high\(^1\). We were able to demonstrate good reliability and repeatability of a novel CT method for the determination of FVA in dogs. In addition we showed that relatively small errors in femoral positioning, as might occur during conventional radiography, led to potentially clinically significant errors in measured FVA.

A standardised and universally applicable system for the assessment of long bone conformation in humans has been described\(^1\). This system has been adopted for the quantification of femoral varus in dogs; the angular relationship of the PAA and the TCA in the frontal plane has been expressed as either the anatomic lateral distal femoral joint angle (aLDFA)\(^{11,17}\) or the femoral varus angle (FVA)\(^{16}\). It has been recognised for some time that due to the normal procurvatum of the canine femur, rotation about an axis perpendicular to the transverse plane will not affect measured TCA but will modify the relative orientation of the PAA, thus artefactually altering measured FVA\(^{16}\). Standardisation of sagittal plane orientation has previously been considered unnecessary (on the basis of the relatively similar diameters of the femoral condyles\(^1\) and results of a previous study\(^{20}\)); our findings however indicate that, at least in femora with FVAs \(\geq 7.9^\circ\), this variable will also artefactually alter measured FVA. Thus standardisation of sagittal plane, as well as rotational, femoral orientation should be considered a prerequisite for the consistent quantification of FVA. Quantification of sagittal plane orientation is challenging using conventional radiography, and definition of rotational orientation is also difficult due to the paucity of definitive radiographic landmarks on a conventional craniocaudal projection. This has led to the use of other criteria including patellar and fabellar position relative to the condylar cortices, and visibility of the tip of the lesser trochanter\(^{11,15-17}\). The consistency of lesser trochanter size and position is to our knowledge unknown; in addition, since patellar and fabellar position may vary with respect to the femur (especially when femoral conformation is abnormal or when MPL is present)\(^9\), this approach is likely to introduce variability in measured FVA. It should be noted that such variability is not apparent in previous studies where observers measured FVA from the same set of radiographs\(^{11,15,16}\); it is likely that intra- and inter-observer variation would have been higher had each femur been both radiographed and measured by each observer. When isotropic spatial resolution is achieved, CT permits reorientation of the femoral image without loss of resolution rendering patient positioning irrelevant, and facilitates definition of landmarks for rotational and sagittal plane orientation which would be impossible using conventional radiography. When viewed from laterally, femoral rotation will cause relative displacement of the caudal aspects of the medial and lateral femoral condyles. When these are superimposed, rotational orientation is defined and a 90° rotation gives a standardised frontal plane image. The low intra- and inter-observer variability reported here is attributed to the standardisation of condylar orientation inherent in the measurement protocol, as well as consistent orientation in the sagittal plane and the independence of measured FVA from patient positioning.

Given the wide range of naturally occurring femoral conformations included in this study it is reasonable to assume that similar precision could be expected in the assessment of clinical cases with MPL. It should however be noted that the described protocol, and the design of the study, is subject to a number of limitations. Firstly, the relationship between the FVA measured using this CT protocol and the previous radiographic technique (and hence accepted ‘normal’ values) is unknown. However, due to breed variation, the multifactorial nature of MPL, and our incomplete knowledge of the contribution of FVA to the development of MPL, at present it is probably best to consider ‘normal’ values as a guide only. Secondly, we made no attempt to quantify femoral torsion which may play a role in the aetopathogenesis of some cases of MPL\(^5\). Measurement of femoral torsion has been following CT\(^{15}\) and may be warranted in addition to FVA assessment in clinical cases of MPL. Thirdly, the 15° angle of caudal inclination used here gives only an approximation of femoral inclination (and hence femorotibial contact) at a normal standing angle. Measurement of FVA at this angle should yield the most clinically relevant value and has been previously recommended\(^{11}\), and also allowed clear visibility of the distal aspects of the femoral condyles. Fourthly, we did not attempt to validate our technique by means of assessment of accuracy by comparison with a gold standard test, as we do not believe that such a test exists at this time. A gold standard test would be capable of quantifying the extent of true ‘FVA and this requires that a definition of ‘true’ FVA must first exist. Regardless of the sophistication and intrinsic accuracy of the imaging technique employed (estimated at +/- 1° in this study\(^5\)), derivation of an absolute value for FVA will always necessitate the use of landmarks which are, ultimately, arbitrary. We would therefore argue that a gold standard test for FVA probably cannot exist, and, in turn, that the concept of absolute

\(\text{b GE Advantage Windows Workstation User Guide}\)
quantification of FVA is illusory. Although, *prima facie*, this concept appears to confound the clinical application of FVA measurement, it must be recognised that, from diagnostic and therapeutic perspectives, the critical value required by the clinician is the angular difference between the FVA of the femur in question and a normal femur. The clinical reliability of this angle is a function of the precision of the FVA measurement technique used, rather than the absolute numeric FVA values it yields (a function of the accuracy of the technique). In an analogous situation, conventional radiographic measurement of tibial plateau angle (TPA) has been shown to be a precise\(^20\), but inaccurate, representation of the anatomic tibial plateau angle\(^21\); tibial plateau levelling procedures are therefore routinely planned on the basis of the difference between precise, but inaccurate, TPA values. This comparison may also be pertinent with respect to the absolute precision of FVA measurement using our CT protocol; our findings suggest that 95\% of measured FVA values will fall within +/- 3° of the mean, compared with +/- 6.5 to 8° for TPA values\(^20\). It is also probable that this level of precision exceeds that which can be achieved surgically both in terms of DFO\(^13\) and other closing wedge ostectomies\(^22\).

In the second part of our study we were able to quantify the error in measured FVA associated with rotational and sagittal plane femoral malpositioning. The relationship between measured FVA and femoral rotation was linear throughout the tested range (between 20 degrees of internal and external rotation) and was minimally affected by the degree of true femoral varus. It is likely therefore that, at least in the femora measured, the degree of femoral procurvatum is independent of femoral varus and thus introduces a consistent error in measured FVA (of almost one degree for every two degrees of rotation). For femora with FVAs ≥ 7.9° the relationship between measured FVA and femoral sagittal plane orientation was also linear throughout the tested range (between zero and 34 degrees of caudal inclination); measured FVA increased by approximately one degree for every six degrees of inclination, a relationship apparently unaffected by the degree of true femoral varus. This relationship did not hold true for femora with true FVAs of -0.4° and 3.8°, where measured FVA was respectively either slightly decreased or was unaffected by increasing femoral inclination. This discrepancy may be explained by consideration of the effect of altered femoral inclination on both the PAA and TCA. When viewed from cranially, increased caudal femoral inclination results in foreshortening. In femora exhibiting varus the proximal diaphysis is medially offset from the condyles in the frontal plane; as foreshortening occurs the angular relationship of these portions of the bone therefore alters, modifying the PAA, and increasing measured FVA. A recent study quantified variations in the diameters of the medial and lateral femoral condyles\(^23\) which would be expected to result in decreased measured FVA as femoral caudal inclination increases due to modification of the TCA. This effect is subtle, but may explain the weak inverse correlation between inclination and measured FVA for the femur with true FVA of -0.4°, as well as the absence of measured FVA increase for the femur with true FVA of 3.8°. In a previous study femoral inclination was reported to have no effect on measured FVA, most probably since the 5.8° average FVA fell below the range where this effect appears to become significant\(^16\). At present it is difficult to estimate the clinical significance of these findings. Firstly, the degree of variation in rotational and sagittal plane positioning following conventional radiography that would be unapparent or considered acceptable by a suitably qualified observer is unknown. On the basis of our observations during the acquisition of data for this study it is our opinion that small variations in positioning are difficult to detect from a cranio-caudal radiographic projection. Secondly, insufficient information is currently available regarding indications for, accuracy of, and outcomes following DFO to estimate the importance of a given variation in initial FVA measurement. Small errors in measured FVA could however lead to inappropriate selection of surgical technique (especially if specific threshold FVA values\(^13\) are applied inflexibly in the selection of DFO candidates), as well as compromising the ability of DFO to realign the quadriceps mechanism. Regardless of these considerations the use of a technique not susceptible to errors arising from femoral malpositioning would seem optimal. The main limitation of the second part of this study was the use of single observations of a limited number of femora. This was considered acceptable given the very low intra- and inter-observer variability associated with the protocol employed, although it is probable that multiple assessments of a greater number of femora would have permitted more detailed assessment. However, in the context of this study, our aim was to demonstrate the importance of standardisation of rotational and sagittal plane orientation rather than to precisely quantify errors resulting from femoral malpositioning.

In conclusion, we demonstrated very low intra- and inter-observer variability in the determination of FVA in dogs using a novel CT method. Using this approach we quantified the errors introduced into FVA measurement by femoral rotational and sagittal plane malpositioning as might occur during conventional radiography. The authors suggest that this CT protocol should be considered for the measurement of FVA and subsequent clinical decision making in dogs clinically affected by patellar luxation.
References


Figure 1 - Protocol for standardised femoral orientation. Perfect superimposition of the most caudal and most distal points of the femoral condyles is achieved (a). An axis is drawn between the most caudal points of the femoral condyles and the proximal femur(b). The image is rotated in the sagittal plane until this axis is vertically orientated (c), and then rotated further such that the axis is caudally inclined by 15°(d). The image is then rotated through 90° in the transverse plane to yield a cranial view of the femur(e). The centre of the diaphysis is identified at 50% and 70% of the distance between the most distal apparent extent of the intertrochanteric fossa and the most proximal apparent extent of the intercondylar notch(f). These points are connected to define the proximal anatomic femoral diaphyseal axis (PAA); the transcondylar axis (TCA) is defined as a line connecting the most distal points of the femoral condyles (g). Femoral varus angle(\(\text{angle } y\)) is the angle between the PAA and a line perpendicular to the TCA (h).
Figure 2 - The relative frequency of the ranges of each series of three FVA measurements made by each observer.

Figure 3 - Variation of measured FVA with rotation for each of six femora with differing average true FVAs. The gradient and R² value for each linear regression line are shown in the key.
Figure 4 - Variation of measured FVA with caudal inclination for each of six femora with differing average true FVAs; the gradient and R² value for each linear regression line are shown in the key.

Tables

Table 1 - Correlation coefficients and P-values describing the relationship between measured FVA and rotation for each of six femora with differing average true FVAs

<table>
<thead>
<tr>
<th>Average true FVA</th>
<th>-0.4°</th>
<th>3.8°</th>
<th>7.9°</th>
<th>11.0°</th>
<th>15.8°</th>
<th>19.0°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation coefficient (95% CI)</td>
<td>-0.996 (-0.999 to -0.991)</td>
<td>-0.997 (-0.999 to -0.993)</td>
<td>-0.993 (-0.997 to -0.983)</td>
<td>-0.994 (-0.998 to -0.984)</td>
<td>-0.995 (-0.998 to -0.987)</td>
<td>-0.993 (-0.997 to -0.982)</td>
</tr>
<tr>
<td>P-value</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

Table 2 - Correlation coefficients and P-values describing the relationship between measured FVA and caudal inclination for each of six femora with differing average true FVAs

<table>
<thead>
<tr>
<th>Average true FVA</th>
<th>-0.4°</th>
<th>3.8°</th>
<th>7.9°</th>
<th>11.0°</th>
<th>15.8°</th>
<th>19.0°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation coefficient (95% CI)</td>
<td>-0.917 (-0.969 to -0.786)</td>
<td>-0.044 (-0.500 to 0.432)</td>
<td>0.987 (0.965 to 0.995)</td>
<td>0.988 (0.968 to 0.996)</td>
<td>0.974 (0.931 to 0.991)</td>
<td>0.976 (0.936 to 0.991)</td>
</tr>
<tr>
<td>P-value</td>
<td>&lt; 0.0001</td>
<td>0.864</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>