The effect of operative technique and tibial osteotomy ratio on post-surgical complications in dogs with medial patella luxation.

By

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LIST OF ABBREVIATIONS

%	Percentage
=	Equal to
AA	Anteversion angle
aLDFA	Anatomical lateral distal femoral angle
BRT	Block recession trochleoplasty
CI	Confidence interval
CT	Computed tomography
CV	Coefficient of variation
FTA	Femoral torsional angle
Kg	Kilogram(s)
K-wire	Kirshner wire
mCdPTA	Mechanical caudal proximal tibial angle
mMDTA	Mechanical medial distal tibial angle
mMPTA	Medial proximal tibial angle
mm	Millimetre
MRI	Magnetic resonance imaging
MPL	Medial patella luxation
n	Number of animals
OA	Osteoarthritis
OROM	Owner-reported outcome measures
OVAH	Onderstepoort Veterinary Academic Hospital
QA	Quadriceps angle
rTTW	Relative tibial tuberosity width
SSI	Surgical site infection
TBW	Tension band wire
TTA	Tibial tuberosity advancement
TTT	Tibial tuberosity transposition
WRT	Wedge recession trochleoplasty

SUMMARY

The effect of operative technique and tibial osteotomy ratio on post-surgical complications in dogs with medial patella luxation.

By

Peter Douglas Guy

Supervisor: Dr Adriaan Kitshoff

Co-Supervisor: Dr Ross Elliott

Department: Companion Animal Clinical Studies

Degree: Masters of Veterinary Medicine (Surgery)

Background: Medial patellar luxation is a common cause of hindlimb lameness in dogs, affecting both small and large breeds. The condition arises from developmental abnormalities and anatomical irregularities in the hindlimb. Tibial tuberosity transposition is a widely used surgical technique for realigning the quadriceps mechanism and treating MPL. Postoperative complications are common following surgical treatment. During the routine evaluation of post operative radiographs, osteotomy segment size appeared to be associated with an increased incidence of complications. This prompted investigation into this possible association between osteotomy segment size and the incidence of complications.

Hypothesis: The complication rate significantly differs when the osteotomized segment of the tibial tuberosity is transposed medially and measures less than 80% of the mid tibial diaphysis on preoperative radiographs

Animals: Client owned dogs (*n*= 88) that underwent MPL surgery

Methods: Records of 88 dogs (108 stifles) that underwent TTT for treatment of MPL were reviewed. Data collected included patient signalment, clinical presentation, surgical factors, pre and postoperative radiographs and complications. The dimensions of tibial tuberosity osteotomy were calculated as a ratio to preselected tibial dimensions based on immediate postoperative radiographs. Mixed-effects logistic regression analysis was performed to determine the impact of osteotomy segment size (O1:D3 ratio) on the occurrence of post-surgical complications following TTT.

Results: Out of 108 surgical procedures performed, 40 (37%) resulted in complications. There was no significant difference in overall complication rates related to patient factors or surgical variables (such as pin direction, tension band, open physis, and complete osteotomy). However, concurrent trochlear augmentation procedures were associated with a decreased risk of complications (hazard ratio (95% CI): 0.31 (0.13 - 0.70), p=0.005). The predicted probability of surgical complications based on the O1:D3 ratio indicated that osteotomy segment sizes between 0.8-0.99 (hazard ratio (95% CI): 0.23 (0.10 – 0.56) p=0.001) and 1-1.19 (hazard ratio (95% CI): 0.05 (0.01 – 0.38), p=0.004) had a lower risk of complications compared to ratios below 0.8 or above 1.2 (hazard ratio (95% CI): 0.26 (0.07 – 0.90), p=0.033).

Conclusions and clinical importance: This study highlighted the clinical importance of considering tibial tuberosity osteotomy segment size in dogs undergoing surgical treatment for MPL by retrospectively analyzing a significant number of cases, the study provided valuable insights into the incidence of postoperative complications related to osteotomy segment size. The findings indicated an association between the O1:D3 ratio (the ratio of osteotomy segment size to preselected tibial dimensions) and the occurrence of complications. Osteotomy segment sizes between 0.8-0.99 and 1-1.19 were associated with a lower risk of complications, while ratios below 0.8 or above 1.2 showed increased risk. Therefore, careful consideration of osteotomy segment size, aiming for sizes equal to or slightly larger than the mid-diaphyseal diameter, is crucial in surgical planning for dogs with MPL.

Keywords: Medial patella luxation, Dogs, Osteotomy segment size, Complications, Trochlear augmentation

CHAPTER 1

1.1 Literature review

1.1.1 Patellar luxation

Patellar luxation is a frequently encountered and diagnosed developmental and occasional traumatic orthopaedic condition in canines [1-4, 8, 16]. Historically, it was believed that small breed dogs were more commonly affected compared to large breeds [4]. However, there is evidence suggesting an increasing prevalence of patellar luxation in large breeds, with MPL being identified as the most common form in this group [1, 3, 4, 8, 17]. The consequences of MPL include mechanical lameness resulting from diminished quadriceps extensor mechanism power, which affects weight-bearing. Additionally, secondary consequences such as osteoarthritis (OA) and synovitis may occur, leading to pain and lameness [1]. Varying reports exist regarding the prevalence of MPL in male and female dogs. Some studies indicated a higher incidence in males [3, 8, 10], while others reported a greater number of affected females [4, 16, 18]. This variation may be attributed to the specific population distribution of large breed males and small breed females in certain countries [3].

Numerous studies have speculated on the etiopathogenesis of MPL in both small and large breed dogs, yet the underlying mechanisms remain poorly understood [4]. The majority of dogs with MPL exhibit anatomical abnormalities affecting the entire pelvic limb. It has been reported that 95% of these dogs have related skeletal deformities [6, 16]. Skeletal abnormalities affecting the femur include coxa vara, coxa valga, decreased angle of anteversion, distal external femoral torsion, femoral varus, and medial femoral condylar hypoplasia. Abnormalities of the tibia include internal proximal tibial torsion, proximal tibial varus or valgus, and medial displacement of the tibial tuberosity. Patellar abnormalities encompass patella hypoplasia and patella alta [1].

Alternative theories regarding the etiopathogenesis of MPL propose a possible hormonal influence leading to a shallow trochlear groove. This, in turn, may cause patellar luxation and dislocation of the stifle extensor mechanism, ultimately contributing to skeletal abnormalities [19]. It has been suggested that the rectus femoris muscle and the cranial head of the sartorius muscle play a significant role in these skeletal changes. Additionally, atrophic changes in the medial thigh muscles, particularly in the rectus femoris head of the quadriceps muscle, may create a bowstring effect that pulls the patella medially, resulting in associated skeletal deformities. In dogs with medial patellar luxation, the cranial head of the sartorius muscle is observed to be located more medially on the wing of the ilium [5, 13].

Femoral coxa vara (reduced angle of inclination of the femoral neck) and coxa valga (increased femoral anteversion) are believed to be caused by malalignment of the quadriceps mechanism, although this connection has yet to be definitively proven [4]. Previously, coxa vara was considered the skeletal abnormality most closely associated with MPL [20]. However, in a large retrospective study, coxa valga was found to be more commonly associated with MPL, primarily in small breed dogs [4]. More recent studies found no significant difference when comparing femoral neck angles in normal dogs to those with MPL [5, 6]. Distal femoral varus, characterized by a medial shift of the long axis of the quadriceps femoris muscles, is one of the more common femoral deformities associated with MPL [6, 21, 22]. Measurement of distal femoral varus is based on the anatomical lateral distal femoral angle (aLDFA) (Fig.1), femoral neck anteversion angles (AA), and femoral torsion angle (FTA) (Fig 2) [1, 6, 23, 24]. Numerous studies have examined the normal aLDFA and FTA in dogs, with computed tomography (CT) measurements showing better agreement with cadaveric specimens compared to radiographs across all studies [25-28]. Radiographs have been found to differ by up to seven degrees when compared to CT in measuring these angles [26, 27]. The normal FTA in small and medium breed dogs ranges from a mean of 18 to 29 degrees in various studies [26, 29]. The normal aLDFA has been reported for several breeds, with smaller breeds having a normal range of 90 to 95 degrees, medium breeds having an aLDFA of 92 to 96 degrees, and large breed dogs having an aLDFA of 94 to 97 degrees [28, 29]. In toy breed dogs with MPL, the aLDFA was found to increase (98 to 102 degrees) in relation to the grade of patellar luxation [29].

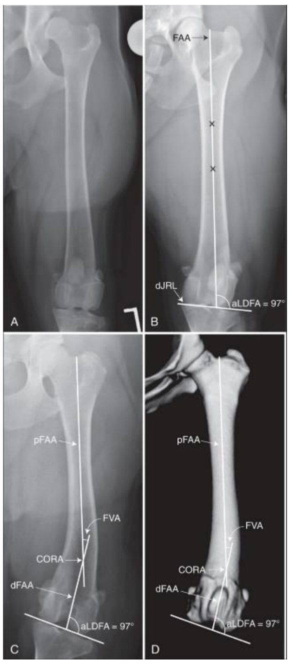

Figure 1. Illustration of the radiographic and computed tomography representation of the anatomic lateral distal femoral angle in dogs with medial patellar luxation, as described by Kowaleski et al. in

2017. This image demonstrates the measurement technique used to evaluate the anatomical lateral distal femoral angle, which is a crucial parameter for assessing angular deformities related to medial patellar luxation

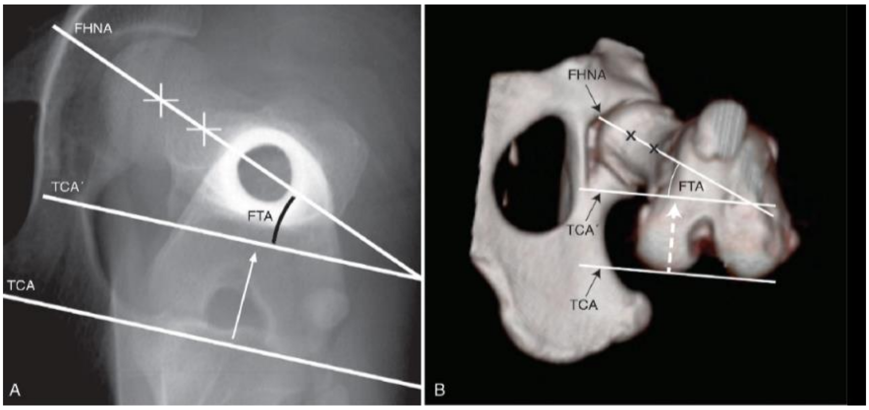

Figure 2. Illustration of the radiographic and computed tomographic representation of the femoral torsion angle in dogs, as described by Kowaleski et al. in 2017. The image demonstrates the measurement technique employed to assess the femoral torsion angle, which is a significant parameter for evaluating femoral rotational deformities in dogs.

The alignment and interaction of various structures in the pelvic limb, including the quadriceps muscle group, patellar trochlear groove, patellar tendon, and tibial tuberosity, play a crucial role in patellofemoral movement. Deformities in the pelvic limb can disrupt the position of these structures, leading to deviations in the force direction of the quadriceps group and resulting in patellar luxation. This deviation is analogous to the quadriceps angle (QA) observed in human orthopaedics, which represents the angle formed between lines connecting specific anatomical landmarks [30, 31]. In dogs, the QA is described as the angle formed between lines connecting the origin of the rectus femoris muscle to the centre of the femoral trochlea and the centre of the femoral trochlea to the tibial tuberosity [30, 33]. A study utilizing magnetic resonance imaging (MRI) to assess the QA in dogs with and without patellar luxation found that as the grade of MPL increases, the average QA also increases [33]. However, the QA alone does not provide specific information about the location and skeletal deformity leading to the misalignment of the quadriceps mechanism and is influenced by the patella's position at the time of measurement [1]. Another study investigated the significance of the preoperative QA deviation from the normal range and found that dogs with postoperative QA values higher than the normal range showed good prognosis without recurrence after surgery [31].

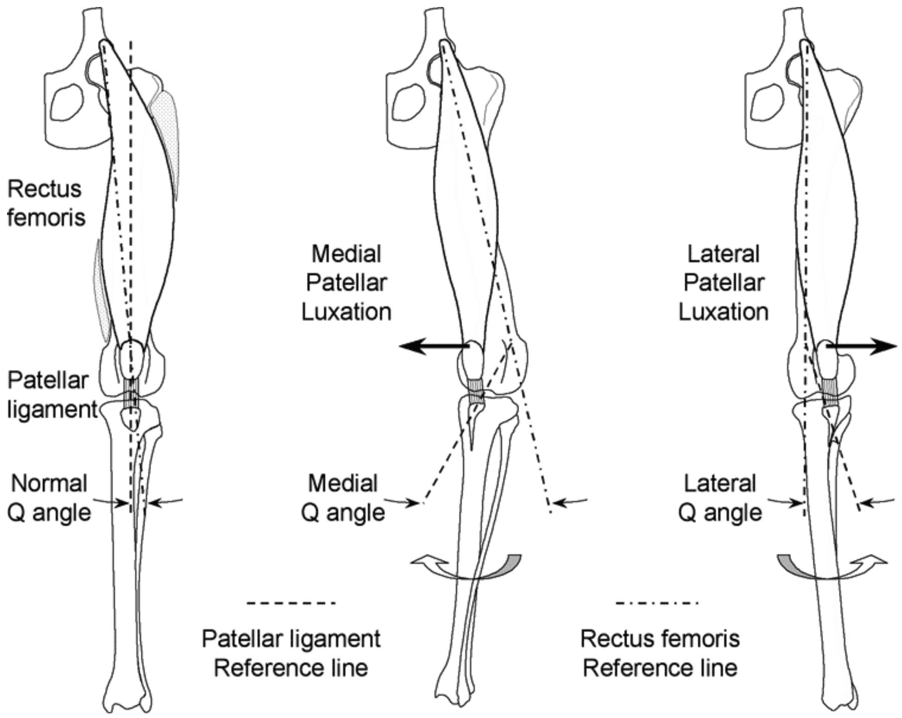

Figure 3. A graphic representation of the Q-angle in dogs, as documented by Hayashi et al. in 2016. The figure visually demonstrates the measurement technique for determining the Q-angle in canines. The Q-angle is the angle formed by two lines: one connecting the origin of the rectus femoris muscle to the centre of the femoral trochlea, and the other connecting the centre of the femoral trochlea to the tibial tuberosity. This angle is essential for assessing the alignment of the quadriceps mechanism and patellar tracking relative to the trochlear groove in dogs. [30]

Tibial deformities often accompany MPL. The most common deformity is internal rotation of the tibia, which results in malpositioning of the tibial tuberosity relative to the femoral diaphysis. This deformity can be primary developmental, leading to a medial positioning of the tibial tuberosity, or it can occur due to a secondary torsional deformity of the proximal tibia [34]. These deformities cause abnormal alignment of the quadriceps mechanism and aberrant patellar tracking in relation to the trochlear groove. A study using CT in toy poodles with MPL found that dogs with grade IV luxation exhibited medial displacement of the tibial tuberosity and internal torsion of the proximal tibia, while dogs with grade II luxation did not show any tibial deformities [6]. Another study in Yorkshire terriers demonstrated that as the grade of medial patellar luxation increases, the incidence of internal torsion of the proximal tibia also increases [34]. This contributes to an increase in the QA [16, 33].

The relationship between MPL and proximal tibial varus or valgus has not been definitively established. However, proximal tibial valgus has been reported in affected dogs as a compensatory change that counteracts distal femoral varus. This characteristic change appears to be more common in dogs with MPL [14, 35, 36]. Normal values for tibial angles on radiographs have been reported to aid in assessing the degree of angular deformity [37]. In a study, it was found that mechanical medial proximal tibial angle (mMPTA) and mechanical medial distal tibial angle (mMDTA) did not significantly differ between toy poodles with and without MPL [6]. However, a higher mMPTA was observed in small breed dogs with grade IV luxation [38]. The same study found that dogs affected by MPL exhibited higher mechanical caudal proximal tibial angle (mCdPTA), but no clear relationship between the incidence of MPL and caudal tibial deformities was identified [38]. Care must be taken when making these measurements, as varus deformities in the proximal tibia may be accurately identified using mMPTA with a tangential caudocranial projection but not with straight caudocranial projections, potentially due to internal and external tibial rotation influencing the accuracy of mMPTA measurements [39].

Figure 4. Computed tomographic representation of the mechanical medial proximal tibial angle, as studied by Yasukawa et al. in 2015. The figure demonstrates the measurement technique utilized to determine the mechanical medial proximal tibial angle. This parameter is crucial for assessing angular deformities in the proximal tibia and offers valuable information for diagnosing and evaluating conditions like medial patellar luxation in dogs.

1.1.2 Surgical treatment

1.1.3 Tibial tuberosity transposition

The primary objectives of surgical treatment for MPL are to realign the extensor mechanism of the stifle joint, improve the positioning of the patella within the trochlear groove to enhance patellofemoral articulation congruity, restore normal biomechanics of the stifle joint and alleviate ongoing mechanical trauma to the articular cartilage [1, 14, 15]. The specific surgical approach is determined on a case-by-case basis, taking into consideration factors such as patient age, size, weight, grade of luxation, underlying skeletal deformities and chronicity [1, 5, 8].

Improvement of the quadriceps mechanism alignment is achieved through a combination of bone and soft tissue techniques, involving corrective osteotomies of the distal femur and proximal tibia [1, 5, 16, 21, 40]. Among these osteotomy techniques, tibial tuberosity transposition (TTT) is considered to be the most important procedure in the majority of MPL cases [5, 11]. Failure to successfully transpose the tibial tuberosity is reported as the most common cause of treatment failure. Tibial tuberosity transposition has been shown to contribute to factors that prevent patellar luxation recurrence, with reported success rates ranging from 8% to 48% [10]. It is important to note that while TTT can address underlying tibial deformities, it may not be necessary if the primary deformity causing misalignment of the quadriceps mechanism is determined to be a femoral deformity.

The primary objective of TTT is to realign the quadriceps extensor mechanism of the stifle joint and reposition the patella within the trochlear groove. The technique was first described by Singleton in 1957 and is based on the Hauser technique used in humans. Tibial tuberosity transposition involves moving a block of bone, along with the attached patellar ligament, to a recipient graft bed [7]. While various technical aspects of the procedure have been described in the literature, there is a lack of objective scientific evidence supporting specific recommendations.

The optimal thickness of the osteotomy segment that needs to be transposed is not clearly defined in the literature. Different studies suggest a minimum thickness ranging from 2-5 mm to approximately 3-5 mm, and some proposed using a triangular portion of the tibial crest or a fragment large enough to accommodate appropriately sized implants such as a cortical screw or two pins [5, 12, 14, 16, 41, 42]. There is also disagreement among authors regarding whether the distal end of the osteotomy fragment should remain attached or be completely separated. Some argue for preservation of the distal periosteum or a small osseous bridge to protect the transplanted tuberosity from being pulled proximally in case of fixation failure. This distal segment may also help transmit forces to the tibia, reducing the reliance on fixation to counteract the tension of the quadriceps mechanism on the tibial tuberosity [9, 12, 14, 40, 42, 43]. Others advocate for complete separation of the osteotomized tuberosity to allow unrestricted repositioning and adjustment for patella alta if present [20, 44]. One study was impartial regarding complete separation or preservation of the osteotomized segment [16].

Previously, it has been hypothesized that a smaller osteotomized tuberosity would result in a more caudal position of the patellar ligament insertion. This could potentially lead to increased retro-patellar pressure, which may cause cartilage damage, further deterioration of preexisting cartilage damage and pain in patients with chondromalacia [5, 45]. A smaller tuberosity segment may also rotate when fixated, resulting in partial contact of the patella with the trochlear groove. The clinical significance of this in dogs is unknown, but it is suspected to alter biomechanics and potentially lead to secondary changes [5, 46]. An alternative approach is to perform a more caudal osteotomy of the tibial tuberosity, providing a larger bone surface for transposition of the fragment without altering the orientation of the patellar ligament.

This results in relocating the patellar ligament in a more cranial position, thereby reducing retro-patellar pressure [5]. Cranialization of the tibial tuberosity is also the basis for dynamic stabilization of cruciate ligament insufficient stifles, as it neutralizes tibio-femoral shear forces by altering the vector of the patellar ligament [47]. However, there is a lack of literature comparing the more traditional TTT technique to a more caudal osteotomy approach. One ex vivo study examined the use of tibial tuberosity advancement (TTA) plates to achieve further lateralization of the osteotomized segment, which yielded favourable results without altering the ligament's orientation [46].

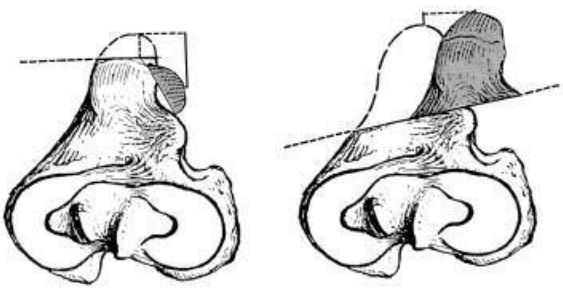

Figure 5. A graphic representation that compares two approaches to TTT, as described by L'Eplattenier and Montavon in 2002. The first approach (left) involves a cranial osteotomized segment of the tibial tuberosity with rotation, while the second approach (right) utilizes a caudal osteotomized segment without rotation but with cranialization. The figure graphically depicts the distinctions between these techniques, emphasizing the positioning and orientation of the tuberosity segment in relation to the tibia

1.1.4 Tibial tuberosity fixation

Achieving adequate fixation of the transposed tibial tuberosity is crucial due to the forces exerted by the quadriceps mechanism. The choice of fixation method depends on factors such as age, weight, unilateral or bilateral disease and activity level of the patient, with specific considerations for large breed dogs [3].

Various fixation methods have been reported in the literature. Initially, Singleton described the use of a wire suture for stabilization of the transposed tuberosity [7], which was later supported by findings from Roush [35]. Other reported methods include single pin fixation [12, 41-43, 48, 49], multiple pin fixation [13, 14, 16, 20, 41, 43, 50] and intramedullary pins [51]. The use of one or two pins with tension band wire (TBW) has also been described [3, 9, 13, 14, 16, 40, 42, 44, 52]. Another approach involves placing a cortical screw in appositional or lag fashion, sometimes accompanied by additional Kirshner wire (K-wires) [13, 53]. Tibial tuberosity advancement plates have been utilized for MPL in a chihuahua with patella baja and MPL, as well as in an ex vivo study demonstrating effective lateralization of the tuberosity with comparable strength to pin and TBW fixation [46, 54]. More recently, TTA plates have been used in cats with concurrent cruciate disease [55].

1.1.5 Pins and tension band wire

The literature shows some variation regarding the placement points and direction of pins when using them for fixation of the osteotomized segment in TTT. Some authors advocate for inserting the pin in a caudoproximal direction to counteract the pull of the quadriceps mechanism and prevent the osteotomized segment from slipping over the pin [12, 16, 20, 42]. Others recommend insertion in a caudodistal/caudomedial direction in conjunction with TBW, taking care to avoid the fossa of the cranial tibial muscle [9, 14, 40]. Another approach suggested is insertion in a medio-proximo-caudal direction to prevent tibial tuberosity migration due to the axial force of the patellar ligament [56]. However, there is a lack of definitive evidence in the literature supporting one method over the other.

In one study, the insertion angle of the K-wire was assessed. It was found that a reduced K-wire insertion angle significantly reduced the risk of avulsion. The reported angles of insertion were 83-111 degrees in patients without avulsion and 55-82 degrees in those with avulsion [15]. This finding was supported by a mechanical study demonstrating increased resistance to tensile loads when the K-wires were directed proximally compared to perpendicular or caudodistal directions [57]. On the contrary, another study found that caudoproximal pin direction was associated with increased risks of complications, although it did not specify any specific type of complication [58].

The addition of TBW has been shown to significantly enhance the strength of the construct used for stabilizing the osteotomized segment [15, 57, 59]. In the absence of TBW, the tuberosity was found to be 11 times more likely to avulse when a single K-wire was used, compared to two or more K-wires [57]. A cadaveric study demonstrated that the addition of TBW significantly increased the strength of a construct with either horizontal or vertical K-wire placement [59]. In large breed dogs, it is recommended to use two K-wires and TBW for fixation of the tibial tuberosity [3]. Some authors suggested using two K-wires with TBW to counter the quadriceps mechanism, which has been associated with a low rate of implant loosening or K-wire migration [14]. In cases where MPL is corrected without femoral trochlear groove deepening, TTT is considered the most critical aspect of the procedure, and supplementary TBW is recommended [9]. However, one study found no major difference in postoperative complications among dogs weighing less than 20 kg when comparing 1 pin, 2 pins, 1 pin with TBW, and 2 pins with TBW [58]. Previous suggestions have been made that repair with TBW could prevent tibial tuberosity fractures [60].

Overall, the reported complication rate associated with pin and TBW fixation of the osteotomized segment, including implant failure and tibial tuberosity fractures, ranges from 3.8% to 4.6% [3, 10].

1.1.6 Complications

The frequency of complications following corrective surgery for patellar luxation can vary significantly, ranging from 6% to 48%. Major and minor complications reported in the literature include reluxation of the patella, migration of TTT implants, tibial tuberosity fracture or avulsion, migration of trochlear wedges, tibial fracture, thickening or rupture of the patellar ligament, peroneal neuropraxia, wound dehiscence, inflammation and infection, progressive osteoarthritis, seroma formation, and cellulitis [1-3, 8-10, 14, 36, 56, 58]. Amongst these, complications associated with implants and patellar reluxation are the most common, followed by avulsion of the tibial crest [15]. Risk factors associated with complications include the grade of patellar luxation, body weight, age, and performing unilateral versus simultaneous bilateral procedures [1]. Increased body weight has been linked to a higher rate of complications [2, 3, 10], and the frequency of complications increases with higher grades of patellar luxation [1, 10, 15, 56]. There is some disagreement in the literature regarding single-session versus staged procedures for bilateral patellar luxation. One study showed that single simultaneous bilateral procedures had a higher complication rate compared to unilateral surgery [61]. However, other studies report comparable rates of complications for single simultaneous bilateral procedures and staged bilateral or unilateral procedures for MPL [62, 63]. Cashmore et al. (2015) found no correlation between weight, age, sex, and simultaneous bilateral procedures [15]. Although most studies agree that age is not a major factor associated with complications [2], it has been reported that the frequency of complications decreases with age, potentially due to postoperative activity level and differences in bone quality [1].

Reluxation of the patella is commonly reported in the literature, with an incidence ranging from 8% to 48%. This appears to be more prevalent in large dogs [2, 3, 9, 10, 15, 58]. However, a significant portion of reluxations are grade 1 luxations that do not cause clinical lameness and do not require additional surgery [5, 36]. With higher grades of patellar luxation and without adequately addressing underlying femoral or tibial skeletal deformities, inadequate TTT, or inadequate depth of the trochlear groove, reluxation is more likely to occur [10, 15, 58]. Release of the cranial belly of the sartorius muscle may reduce the incidence of reluxation [15].

Implant failures are among the most common complications in MPL surgeries, with initial surgical complication rates ranging from 1.5% to 8.1% and revision surgery rates as high as 6.2% to 55.6% [15, 56]. Surgical revision may be necessary due to pin migration, broken pins causing pain and discomfort, pins placed too eccentrically in the tibial tuberosity, or infection [15, 56].

1.2 Conclusions of the literature review

Medial patella luxation (MPL) is a common congenital orthopaedic condition in dogs that can significantly impact their mobility and quality of life. While it was previously more commonly seen in small and toy breed dogs, there has been an increasing incidence of MPL in large breed dogs as well [3]. The exact cause of MPL is still debated, but there is a general consensus that underlying anatomical abnormalities play a significant role in its development [6,16]. Abnormalities in the femur and tibia have been investigated and reported in relation to MPL [6,14,21,22,34,35,36]. Surgical realignment of the quadriceps mechanism is the primary approach for treating MPL, and there are various methods used for this purpose. Among these methods, TTT has been identified as a crucial technique [5,11]. Tibial tuberosity transposition has demonstrated a significant role in mitigating the factors that contribute to the recurrence of patellar luxation, a prevalent postoperative complication often associated with surgical treatment of MPL [10]. The ideal dimensions of the tibial osteotomy in the context of MPL have not been clearly defined, and existing guidelines do not adequately address the growing population of large breed dogs affected by MPL. Earlier hypotheses have proposed the utilization of a larger osteotomy segment to diminish retro patellar pressure, consequently reducing the occurrence of postoperative complications linked to the procedure [5,52]. The frequency of complications associated with osteotomy segment size has not been extensively explored and constitutes the primary objective of the present investigation.

1.3 Project justification

Patients presenting with hind limb lameness at Onderstepoort Veterinary Academic Hospital (OVAH) frequently exhibit MPL, which is commonly treated with TTT. During the assessment of radiographs and follow-up evaluations for complications, it was observed that patients with relatively small tibial tuberosity segment following osteotomies experienced a higher incidence of complications (unpublished data). There is variation among surgeons in the treatment of MPL, and preoperative evaluation of osteotomy segment size is not consistently performed on an individual basis. Establishing uniformity among surgeons and determining the optimal osteotomy segment size for each patient is crucial in achieving higher surgical success rates and reducing complications. Insufficient osteotomy segment size in the past has resulted in residual instability and complications. The size of the osteotomy can also impact postoperative recovery and functional outcomes in these patients. Adequate osteotomy segment size promotes optimal healing and alignment of the quadriceps mechanism, while inappropriate size can lead to prolonged healing and impaired limb function. Anatomical differences between small and large breed dogs may influence surgical outcomes in MPL cases. Small dogs may have increased instability due to a shallower trochlear groove and altered Q angle, while large breeds may experience higher joint forces due to their size and weight. Evaluating osteotomy segment size can provide valuable breed-specific guidelines tailored to the individual needs of patients. To the best of the author's knowledge, no definitive data has been published regarding the ideal osteotomy segment size for patients undergoing surgical treatment for MPL in dogs.

CHAPTER 2

2.1 Aims and objectives

This project aimed to achieve several objectives related to TTT in dogs undergoing surgical correction for MPL. The primary objective is to determine the optimal size for the osteotomy based on preoperative radiographs by calculating ratios of tibial diameter and establishing proportional measurements. These measurements are then correlated with postoperative outcomes and complications to identify the optimal size for the osteotomized segment.

The secondary objective of the project is to assess the likelihood of complications associated with the utilization of additional surgical factors. To accomplish this, a large cohort of dogs that underwent surgical treatment for MPL was included in the study. Surgical factors were identified and documented and postoperative outcomes and complications were monitored. The data collected allow for the analysis of the likelihood of complications in relation to the utilization of specific surgical factors.

Another secondary objective of the project is to evaluate the interobserver variability in radiographic measurements of the osteotomized segment. Preoperative radiographs of dogs that underwent TTT for MPL were used for this evaluation. The variability among different observers (interobserver variability) was assessed. The data analysis aimed to determine the level of agreement and variability in these radiographic measurements.

By accomplishing these objectives, this project aimed to provide valuable insights into determining the optimal size for the tibial tuberosity osteotomy, assessing the impact of additional surgical factors on complications and understanding the accuracy or dependability of radiographic measurements in TTT procedures for MPL.

2.2 Hypotheses

2.2.1 Primary hypothesis

H_0: There is no significant difference in complication rates among various osteotomy segment ratios of the tibial tuberosity transposed medially, considering preoperative radiographs.

H_1: A significant difference exists in complication rates across different osteotomy segment ratios of the tibial tuberosity transposed medially, considering preoperative radiographs.

2.2.2 Secondary hypothesis

H_0: There is no significant difference in complication rate for patient or surgical factors in dogs undergoing surgical treatment for MPL.

H_1: There is a significant difference in complication rate for patient or surgical factors in dogs undergoing surgical treatment for MPL.

2.3 Benefits arising from the study

The project has several potential benefits:

- Improved patient outcomes: By determining an optimal measurement for the osteotomized segment based on preoperative radiographs, tailored to each patient regardless of size, the study aims to reduce the potential for complications arising from the surgical treatment of MPL.
- Individualized treatment approach: The study's findings will allow clinicians to individualize the surgical treatment for MPL based on the specific measurement of the osteotomized segment. This individualized approach can enhance surgical precision and optimize the realignment of the quadriceps extensor mechanism, leading to improved patellofemoral articulation congruity and better restoration of normal stifle biomechanics.
- Reduced complications and revision surgeries: With a more accurate and tailored measurement for the osteotomized segment, the study aims to minimize the occurrence of postoperative complications. By reducing complications such as implant failures, reluxation of the patella, and tibial crest avulsion, the need for revision surgeries can be significantly reduced. This can improve patient outcomes and reduce the burden on both the patient and the owner.
- Enhanced evidence-based decision-making: The study will contribute further evidence to the current literature on MPL treatment, specifically regarding the measurement of the osteotomized segment. By adding to the existing knowledge, the project will enable clinicians to make more informed and evidence-based decisions when selecting the appropriate treatment approach for MPL. This can improve the overall quality of care provided to patients.

In summary, the project aims to improve patient outcomes, reduce complications, and guide clinicians in their treatment selection for MPL by providing an optimal measurement for the osteotomized segment based on preoperative radiographs. The potential benefits include enhanced surgical precision, individualized treatment, reduced complications and revision surgeries, and evidence-based decision-making.

CHAPTER 3

3.1 Materials and methods

3.1.1 Model system

This project is a retrospective analysis of medical records and radiographs of dogs that were admitted to OVAH, University of Pretoria, South Africa, from April 2015 to March 2022, and diagnosed with MPL and subsequently underwent surgical treatment. The study received ethical approval from the animal ethics committee of the University of Pretoria (REC144-21). The approval document can be found in Appendix A of the study.

3.1.2 Experimental design

In this study, a total of 346 dogs that were presented to OVAH, with a confirmed diagnosis of congenital MPL and underwent TTT were to be included for analysis.

The inclusion criteria:

- Dogs with a diagnosis of congenital MPL confirmed through physical examination and radiographic findings, who subsequently underwent TTT.
- Availability of pre-operative, post-operative, and follow-up radiographs demonstrating clinical union of the osteotomy.
- Detailed surgical reports and information on post-operative treatment.
- Additionally, descriptions of any treatments provided for complications were considered.

Exclusion criteria:

- Dogs suspected of having traumatic patella luxation
- Dogs with bidirectional patella luxations.
- Dogs who underwent a distal femoral osteotomy (DFO) instead of tibial crest transposition.
- Dogs with concurrent orthopedic diseases such as cranial cruciate ligament rupture, neurological abnormalities, or a history of previous surgery on the affected pelvic limb were also excluded from the analysis.

These criteria were included to ensure the homogeneity of the study population and to focus specifically on dogs with congenital MPL who underwent TTT for treatment.

3.1.3 Experimental procedure

3.1.3.1 Case selection and treatment

For case selection, the medical records were searched to identify dogs that underwent surgical treatment for MPL between 2015 and 2022. Dogs that met the exclusion criteria mentioned previously were excluded from the study. However, if these dogs presented during the study period for treatment of the contra-lateral limb for MPL, they were included as a separate statistical case.

Information retrieved from the records included the signalment of the dogs (breed, age, sex), findings from the orthopedic examination, preoperative grade of MPL based on the grading system published by Roush in 1993 [16]. Preoperative and post-operative orthogonal radiographs were obtained using an X-ray machine (Baccara 90/25 HV (Apelum DMS group, France). The type of surgical treatment performed, intraoperative and postoperative complications, and any additional surgical or medical management required was noted.

The grading system for MPL used in the study was as follows:

- Grade 1: The patella can be manually luxated with pressure but returns to a normal position in the femoral trochlea when released.
- Grade 2: The patella may luxate during stifle flexion and rotation of the paw or manual manipulation and remains luxated until stifle extension or manual replacement occurs.
- Grade 3: The patella is permanently luxated but can be manually replaced. It reluxates spontaneously when manual pressure is removed.
- Grade 4: The patella is permanently luxated and cannot be reduced manually.

The surgical techniques performed intraoperatively to provide stability of the patella included, but were not limited to, medial soft tissue release (medial desmotomy), lateral capsule and retinaculum imbrication, block recession trochleoplasty (BRT), wedge recession trochleoplasty (WRT), medial Ridgestop (Ridgestop^{TM}, Orthomed UK) trochlear augmentation, and TTT. The surgical approach, either lateral or medial parapatellar, and arthrotomy to evaluate the femoral trochlear groove, patellar articular cartilage, cruciate ligaments, medial and lateral meniscus, were noted.

For TTT, the lateral transposition of the tibial tuberosity will have been performed. It was noted if the distal segment of the osteotomy was left intact or completely cut. The method of stabilization, including the use of one or two K-wires with or without TBW, and whether a lateral fabello tibial suture was placed was also recorded. The point of insertion of the K-wire (proximal, at the level, or distal) to the tibial tuberosity and the direction of insertion (in degrees) being caudoproximal, caudodistal, or perpendicular to the tibia's long axis was documented (Figure 6).

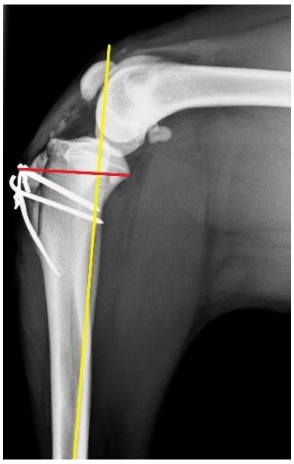

Figure 6. Illustration of the measurement of the pin angle during the surgical procedure. The long axis of the tibia is identified and a line perpendicular to this axis is drawn (red line). The direction of the K-wire insertion is determined based on this line and recorded as caudodistal, caudoproximal, or perpendicular to the tibia's long axis (yellow line).

3.1.3.2 Osteotomy segment size

Postoperative mediolateral radiographs were used to measure relative osteotomy segment size. All radiographic measurements were taken using digital software (RadiAnt Windows version 11/10/8.1/8/7; Mexidant, Poznan, Poland) by one certified small animal radiologist, certified small animal specialist and one small animal surgical resident. Osteotomy segment ratio (Fig.7) was calculated based on a percentage from other tibial measurements. D1 taken as the width of the tibia at the widest point of the osteotomy. This measured from the point of the tibial tuberosity to the caudal cortex of the tibia. D2 from the cranial border of the tibial crest as it tapers from the tibial tuberosity to the caudal edge of the tibia. D3 taken from the edge of the cranial tibial cortex at a point mid diaphyseal to the caudal edge of the caudal tibial cortex. The mid diaphyseal measurement was selected due to the anatomical shape of the tibia at this point. Given the more cylindrical nature this helped minimize variation in measurement of the radiographs. This measurement also correlates to a similar location of distal tibial width described by Mostafa et al. [65,66]. O1 was the measurement of the osteotomy segment size from the most cranial edge of the insertion of the patella ligament on the tibial tuberosity to the osteotomy line. O2 was taken from the proximal to distal end of the osteotomy cut.

Figure 7. Mediolateral radiographs used to measure relative osteotomy ratios, defined as D1: width of the tibia at the widest point of the osteotomy (dashed black line), D2: cranial border of the tibial crest as it tapers from the tibial tuberosity to the caudal edge of the tibia, D3: edge of the cranial tibial cortex at a point mid diaphyseal to the caudal edge of the caudal tibial cortex, O1: Osteotomy segment size from most cranial edge of the insertion of patella ligament to osteotomy line (solid black line), O2: osteotomy cut.

3.1.3.3 Follow up

Dogs were re-examined by a specialist or a resident under specialist supervision at the OVAH at 6 weeks following surgery. Orthogonal radiographs were taken to assess for bone healing and implant stability, and patients were evaluated for clinical progression. Any dogs that experienced a clinical deterioration before 6 weeks were examined by a surgeon sooner with repeat radiographs to evaluate for complications. The assessment of complications was continued until the point when the complication was resolved or managed. The classification of complications followed the standardized criteria provided by Cook et al. [64]. Major complications were those that necessitated revision surgical treatment. Minor complications encompassed those that could be managed with medical interventions.

Regarding the time frames for data collection, the following categories were used:

- Perioperative (pre, intra, and postoperative): 0-3 months
- Short term: >3-6 months
- Midterm: >6-12 months
- Long term: >12 months

During each of these intervals, complications were identified and documented accordingly.

3.1.3.4 Interobserver variability

To assess inter-observer variability, all identifying information was removed from the digital radiographs. Personnel conducting the measurements were individually shown and provided with an image illustrating the measurement technique. Additionally, all personnel were blinded to measurements conducted by others. Three observers (specialist small animal surgeon, specialist small animal radiologist and a small animal surgical resident) then performed tibial measurement as described on all 108 radiographs extracted. Interobserver repeatability was then calculated as a coefficient of variation for all 108 limbs.

3.1.4 Data analyses

The normality assumption for quantitative measurement data was assessed by calculating descriptive statistics, plotting histograms, and performing the Anderson-Darling test in commercial software (MINITAB Statistical Software, Release 13.32, Minitab Inc, State College, Pennsylvania, USA). Data were descriptively presented using box, scatter, and line plots generated using the ggplot2 package within R. Inter-observer repeatability was evaluated by calculating the coefficient of variation (CV) as the standard deviation divided by the mean for the three independent evaluators. The accuracy of the O1:D3 ratio for predicting post-surgical complications was initially evaluated using mixed-effects logistic regression incorporating a random effect term for dog (bilateral surgery performed in some study animals) and modelling using polynomial terms but no other covariates. The O1:D3 ratio was subsequently categorized as < 0.8, 0.8 – 0.99, 1 – 1.19, and ≥ 1.2 based on the results of the mixed-effects logistic regression. Age and weight were classified into three categories each based on biologically reasonable values and an effort to create levels with approximately equal sample numbers. The effect of the O1:D3 ratio and other potential predictors on post-surgical complication incidence was estimated using Cox proportional hazards analysis. Univariate screening models were fit and all variables with Wald P < 0.2 were selected for multivariable models. Multivariable models were fit using a manual backwards stepwise approach starting with all selected variables from the univariate screening models and removing variables one-by-one based on the largest Wald P value until all remaining variables were P < 0.05. All Cox models were stratified to adjust for lack of independence with all dogs having unilateral surgery placed into a single strata and individual strata created for the dogs having bilateral surgery. Effect sizes were estimated by calculating the hazard ratio and its corresponding 95% confidence interval (CI). Unless stated otherwise, all statistical analyses were performed within commercial software (IBM SPSS Statistics Version 28, International Business Machines Corp., Armonk, NY, USA) with significance set as $P < 0.05$.

3.2 Project management

3.2.1 Experimental animals

All animals involved in this study were presented at the OVAH for treatment of MPL. Initial diagnosis followed by surgical treatment for MPL would have been performed. Animals were then seen for follow up examination at 6-8 weeks. All data collected was retrospective.

3.2.2 Staff, laboratories, facilities, equipment and supplies

3.2.2.1 Staff

Primary investigator: Dr Peter Guy (External resident, Department of Companion Animal Clinical Studies, University of Pretoria, South Africa)

- Project design
- Protocol drafting
- Data collection
- Data interpretation and analysis
- Dissertation drafting
- Mini dissertation drafting

Research supervisor: Dr Adriaan Kitshoff (Department of Companion Animal Clinical Studies, University of Pretoria, South Africa)

- Manuscript drafting
- Data collection

Co-supervisor: Dr Ross Elliott (Department of Companion Animal Clinical Studies, University of Pretoria, South Africa)

- Project conception and design
- Manuscript drafting
- Data collection
- Data analysis

Co-investigator: Dr Christelle Le Roux (BVSc Hons. MMedVet (Diag Im) DipECVDI)

- Data collection
- Data analysis

Co-researcher: Prof Geoff Fosgate (Department of Production Animal Studies, University of Pretoria, South Africa)

- Data collection
- Statistical analysis

Sr Tamarin Fischer (Department of Companion Animal Clinical Studies, University of Pretoria, South Africa)

- Case collection and evaluation

3.2.2.2 Facilities

The study was conducted in the Small Animal Surgical and Diagnostic Imaging Sections, Department of Companion Animals Clinical Studies of the OVAH.

3.2.2.3 Equipment and supplies

All equipment used was from the Faculty of Veterinary Science, University of Pretoria.

CHAPTER 4

4.1 Results

4.1.1 Study population descriptors

In total, 346 dogs receiving TTT for MPL, 88 met inclusion criteria (total of 108 stifles). Of these, 43 (48.8%) were spayed females, 27 (30.6%) were neutered males, 10 (11.3%) were intact females, and 8 (9%) were intact males. Median age was 36 months (range: 6-135) with a median weight of 9.7 kg (range: 2.2-50 kg). Dogs weighing < 5 kg constituted 37%, 5-9.9 kg 31.5%, and >10 kg 31.5%. This study encompassed 28 breeds, primarily Yorkshire terriers (n=15), Pomeranians (n=14), and Chihuahuas (n=9). Pre-surgery, 5.5% had grade 1, 48% grade 2, 36% grade 3, and 10% grade 4 patellar luxation. Most (77%) had unilateral luxation, 23% bilateral, with various surgical procedures performed. Follow-up median was 42 days (range: 10-1075). Results are summarized in Table 1

4.1.2 Complications

Of the 108 stifles, 40 (37%) encountered complications (Figure 8). Sixteen (14.8%) were major, including recurrent patella luxation requiring further surgery (9 cases), tibial tuberosity avulsion (3 cases), and other issues. Minor complications (24, 22.2%) involved recurrent patella luxation (15 cases), tibial tuberosity avulsion (5 cases), and implant-related concerns. Most complications (31) occurred perioperatively, with a mean occurrence time of 111 days (range: 6-1108 days). Fewer complications emerged beyond 3 months post-surgery (Table 2)

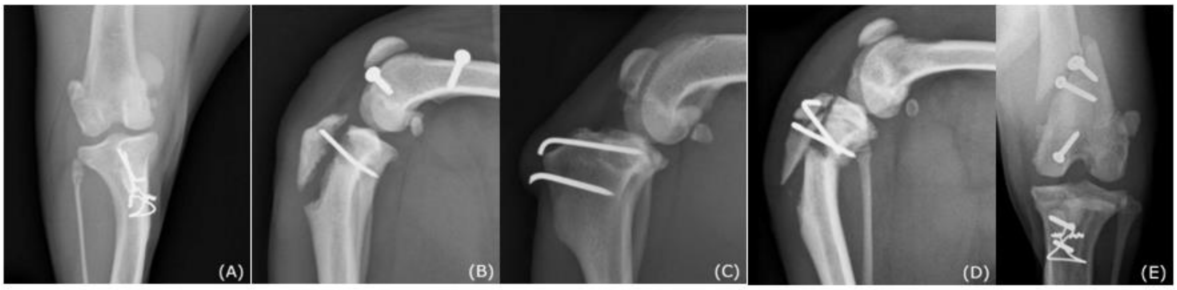

Figure 8. Representative follow up radiographs of postoperative complications associated with surgery for medial patella luxation. (A, B) Patella relaxation and tibial tuberosity avulsion represent the most common complications noted. (C) Minor complications associated with pin insertion. (D, E) Major complications of tibial and femoral fracture following surgery to treat medial patella luxation.

4.1.3 Risk factors associated with complications of surgery

The study investigated various factors linked to complications following osteotomy, considering patient and surgical variables. Patient-specific factors did not show significant association with increased complication rates. Notably, trochlear augmentation, completeness of osteotomy, and specific ranges of the O1:D3 ratio indicated a reduced likelihood of complications. Detailed findings are available in Table 1.In the multivariate analysis, only trochlear augmentation and the O1:D3 ratio retained significance (Table 2). Trochlear augmentation (BRT, WRT, Ridgestop) was notably linked to a reduced complication rate (hazard ratio (95% CI): 0.31 (0.13 – 0.70), p=0.005). Among the 64 surgeries with additional procedures, specific complications were observed: 4 out of 13 surgeries with BRT encountered complications (6.15%), 5 out of 27 with WRT (7.69%), no additional complications were noted with anti-rotational sutures, and 9 out of 18 with a medial Ridgestop (13.8%). These details are summarized in the studies data.

According to the predicted probability (Figure 9), the O1:D3 ratio revealed an increased complication risk when the osteotomy was <0.8 and a protective effect in the 1-1.19 range. For osteotomies <0.8, complications occurred in 52% (21/40), with 12 major and 9 minor complications. In the 0.8-0.99 range, 30% (12/40) experienced complications, split evenly between major and minor. Osteotomies in the 1-1.19 range saw a 7.5% (3/40) complication rate, all minor. When >1.2, complications were 10% (4/40), one major and three minor. The O1:D3 ratio of 1-1.19 showed the strongest protective effect (hazard ratio (95% CI): 0.05 (0.01-0.38), p=0.004) against complications (Figure 3).

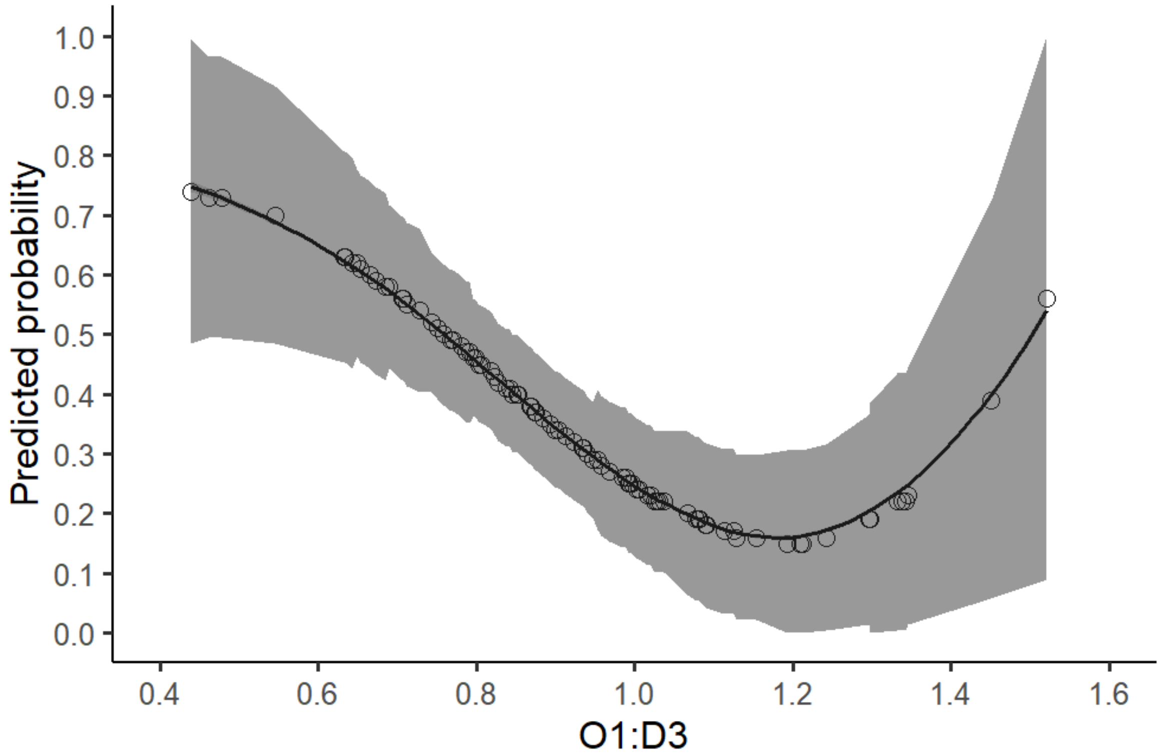

Figure 9. Predicted probability of a surgical complication based on the O1:D3 ratio for 108 limbs evaluated in 88 dogs presenting for tibial tuberosity transposition to correct medial patella luxation. Probabilities calculated using mixed-effects logistic regression incorporating a random effect for dog to

account for bilateral surgery in some dogs and modelling the O1:D3 ratio using polynomials. Circles represent predicted probabilities, the solid line represents a smoothed estimate, and the shaded area corresponds to a 95% confidence band.

4.1.4 Interobserver variability

The level of interobserver variability for the different tibial measurements are depicted in Figure 10. The coefficient of variation showed consistency in values for all parameters of interest between observers

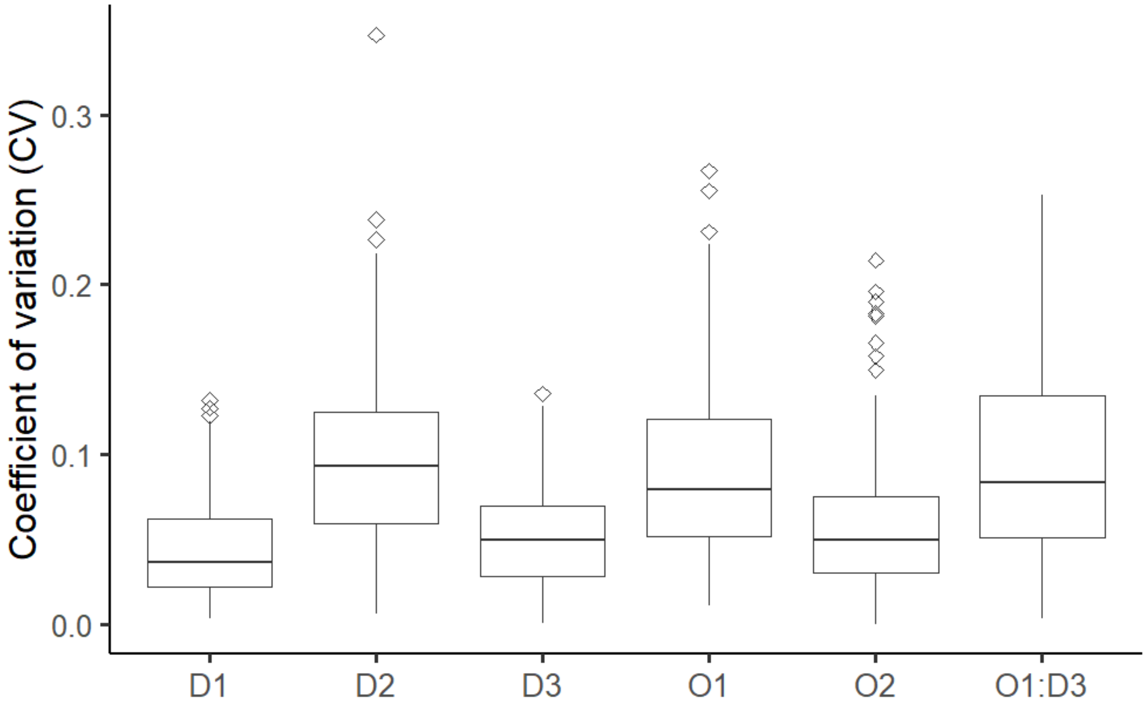

Figure 10. Inter-observer repeatability presented as the coefficient of variation (CV) for measurements from three observers for 108 limbs evaluated in 88 dogs presenting for tibial tuberosity transposition to correct medial patella luxation.

Table 1. Univariate associations between dog and surgery covariates and the rate of complication development after tibial tuberosity transposition in 108 limbs from 88 dogs admitted for surgery to correct medial patella luxation from a single veterinary teaching hospital between April 2015 and March 2022.

Variable	**Level**	**Parameter estimate ($\hat{\beta}$)**	**Hazard ratio (95% CI)**	**P value**
Sex	Male	0.055	1.06 (0.48, 2.33)	0.891
	Female	Referent		
Age	< 2 years	0.953	2.59 (0.83, 8.08)	0.100
	2 – 4.9 years	0.894	2.44 (0.76, 7.83)	0.132
	≥ 5 years	Referent		

Weight	< 5 kg	Referent		
	5 – 9.9 kg	-0.185	0.83 (0.29, 2.40)	0.731
	≥ 10 kg	0.202	1.22 (0.49, 3.04)	0.664
Breed	Yorkshire terrier	-1.130	0.32 (0.07, 1.41)	0.132
	Pug	0.734	2.08 (0.60, 7.20)	0.245
	Chihuahua	-0.788	0.46 (0.06, 3.43)	0.445
	Pomeranian	-0.305	0.74 (0.22, 2.53)	0.628
	Other breed	Referent		
Luxation grade	1&2	1.251	3.49 (0.34, 35.7)	0.291
	3	0.648	1.91 (0.20, 18.4)	0.575
	4	Referent		
Limb	Left	0.541	1.72 (0.86, 3.41)	0.123
	Right	Referent		
Trochlear augmentation	Yes	-0.835	0.43 (0.19, 0.98)	0.043
	No	Referent		
Pin direction	Caudodistal	-0.144	0.87 (0.39, 1.91)	0.722
	Caudoproximal	0.564	1.76 (0.52, 5.97)	0.366
	Parallel	Referent		
Tension band	Yes	0.233	1.26 (0.59, 2.70)	0.547
	No	Referent		
Open physis	Yes	0.421	1.52 (0.57, 4.06)	0.401
	No	Referent		
Complete osteotomy	Yes	0.839	2.31 (1.01, 5.29)	0.047
	No	Referent		
O1:D3 ratio	< 0.8	Referent		
	0.8 – 0.99	-1.238	0.29 (0.12, 0.70)	0.006
	1 – 1.19	-2.795	0.06 (0.01, 0.51)	0.010
	≥ 1.2	-1.248	0.29 (0.08, 0.99)	0.048

CI = confidence interval.

Table 2. Multivariable associations between surgery covariates and the rate of complication development after tibial tuberosity transposition in 108 limbs from 88 dogs admitted for surgery to correct medial patella luxation from a single veterinary teaching hospital between April 2015 and March 2022.

Variable	**Level**	**Parameter estimate ($\hat{\beta}$)**	**Hazard ratio (95% CI)**	**P value**
Trochlear augmentation	Yes	-1.185	0.31 (0.13, 0.70)	0.005
	No	Referent		
O1:D3 ratio	< 0.8	Referent		
	0.8 – 0.99	-1.465	0.23 (0.10, 0.56)	0.001
	1 – 1.19	-3.069	0.05 (0.01, 0.38)	0.004
	≥ 1.2	-1.364	0.26 (0.07, 0.90)	0.033

CI = confidence interval.

CHAPTER 5

5.1 Discussion

The findings of this study supported the ratio of tibial osteotomy segment size to the tibial diaphysis size, as well as the use of trochlear augmentation, are associated with a significant reduction in the occurrence of postoperative complications. Importantly, these associations remain consistent across all sizes of dogs. Specifically, tibial osteotomies with an O1:D3 ratio between 1-1.19, along with the inclusion of trochlear augmentation techniques (BRT, WRT, Ridgestop), were found to be linked to a decrease in post-surgical complications. Conversely, tibial osteotomies with an O1:D3 ratio below 0.8 were associated with an increase in postoperative complications.

The overall complication rate of 37% and the 14.8% incidence of major complications observed in this study following initial patella stabilization align with previously reported rates in the literature [2,3,10,15,56,58]. Patella reluxation rates have been reported to range from 8% to 48% in previous studies [1,3,10,15], which was similar with the findings of this study where 22% of cases experienced reluxation. Amongst these cases, 8.3% required revision surgery due to major complications, while 13.8% experienced minor complications that were managed non-surgically. The higher incidence of reluxation may be attributed to concurrent skeletal deformities and the inadequate assessment of these factors prior to surgery. Additionally, insufficient lateralization of TTT to restore quadriceps alignment and patella tracking could contribute to the increased risk of reluxation. Previous research reported that the risk of reluxation is reduced when trochleoplasty is performed alongside TTT, with dogs being five times less likely to experience patella reluxation in such cases [15]. This finding was supported by the current study, which demonstrated a decrease in complications when any form of trochleoplasty or trochlear augmentation was added to the surgical procedure (95% CI: 0.31 (0.13, 0.70) P=0.005).

The second most common complication observed in this study was tibial tuberosity avulsion. The reported incidence of tibial tuberosity avulsion in previous studies ranges from 3.8% to 4.6% [1]. In this study, the overall incidence of tibial tuberosity avulsion complications was 7.4%, with 2.7% classified as major and 4.6% as minor. These percentages are higher compared to the rates reported in other studies. One possible explanation for this discrepancy is that a larger proportion of the patients in this study did not have a TBW placed. Previous research has shown that the inclusion of TBW in the surgical construct following TTT results in lower rates of tibial tuberosity avulsion and provides added strength to the construct [15,59]. Regarding pin direction following TTT, previous studies have investigated this factor and demonstrated that transverse pin placement leads to increased construct strength and reduced complications compared to caudodistal pin placement [15,57,67]. However, this study did not identify an association between pin direction and the occurrence of complications.

Interestingly, a significant proportion of cases that underwent trochlear augmentation with a medial Ridgestop implant experienced complications. Out of the 18 cases that had a Ridgestop implant, 9 (50%) suffered complications. Amongst these, 7 were classified as major complications and required additional surgical intervention, while 2 were considered minor. There is a lack of comprehensive reports on the short to medium-term outcomes of the Ridgestop implant. However, one available abstract described a follow-up of 17 cases ranging from 1 to 18 months. In this study, 14 out of 17 dogs showed resolution of clinical signs, while 3 required implant removal and revision using traditional techniques, and 1 had incomplete resolution [68]. Another study examined the outcomes of 43 dogs treated with the Ridgestop implant, either as a stand-alone procedure or in combination with traditional techniques. The overall complication rate was reported as 13%, with 2 out of 43 cases requiring revision surgery. The study reported an overall success rate of 97.7% after 6 months [69]. In this particular study, the complication rate was higher in cases that received the Ridgestop implant (8.3%) compared to more traditional trochleoplasty techniques such as BRT (3.7%) and WRT (4.6%). The higher incidence of complications associated with the Ridgestop implant may be attributed to patient size, as a larger portion of the patients in this study weighed over 10 kg (50%), whereas a previous study reported that 65% of patients were under 10kg [69]. The addition of a Ridgestop implant may increase retro-patellar pressure, potentially resulting in the patella riding against the Ridgestop and creating a condition similar to Wiberg syndrome observed in humans. Considering the higher complication rate associated with the Ridgestop implant compared to BRT and WRT, further investigation is required to fully evaluate its efficacy and safety in patella luxation surgery.

When investigating the relationship between tibial tuberosity osteotomy segment size and the likelihood of complications in this study, multiple variable analysis revealed notable findings. It was observed that a smaller osteotomized tuberosity, with an O1:D3 ratio below 0.8, was associated with a higher predicted probability of complications. In contrast, an osteotomy ratio between 1 and 1.19 showed a more protective effect, resulting in a lower likelihood of complications. The underlying reason for these results can be attributed to a hypothesis suggesting that a small osteotomized tuberosity being transposed would lead to a more caudal position of the patellar ligament insertion. Consequently, this may increase retro-patellar pressure, causing cartilage damage, exacerbating existing cartilage damage, and resulting in pain due to continued chondromalacia [5,45].

Moreover, a more caudal osteotomy and subsequent cranialization of the osteotomy segment were associated with reduced medial contact pressure. This reduction in pressure may help prevent recurrent luxation, as observed in cases with an osteotomy ratio of 1-1.19 in this study. The altered orientation of the patellar ligament resulting from a smaller osteotomy is suspected to have biomechanical implications for the stifle joint, potentially leading to secondary changes and an increased risk of complications [5,46].

This hypothesis by L'Eplattenier [5] was further supported by a recent ex vivo biomechanical study that assessed patellofemoral contact pressures following TTT. The study demonstrated that cranio-lateralization of the tibial tuberosity resulted in a reduction of total, medial, and central contact pressures, while lateral contact pressure remained unchanged. Conversely, caudo-lateralization of the tibial tuberosity, which aligns with the traditional approach to TTT, led to increased total and lateral contact pressures without a reduction in medial contact pressure [45].

Clinical observations from a study involving 20 cases, where a caudal osteotomy was performed to facilitate cranialization of the tibial tuberosity, demonstrated favorable outcomes. More than 60% of the animals exhibited no lameness during the 15-month follow-up period, indicating a successful outcome within the context of the study. Furthermore, the study reported a low incidence of complications, with only one case documenting implant failure [52]. It is worth noting that only one other study has reported osteotomy segment size in relation to complications in MPL. This study did not find a correlation when assessing osteotomy segment size in relation to tibial width at the same level. However, the author did recommend the use of a larger osteotomy segment [2]. These findings highlighted the need for further investigation and research to better understand the optimal osteotomy segment size and its impact on post-operative outcomes in MPL cases.

Recent reports have primarily focused on evaluating the radiological aspects of bone morphology in dogs with MPL. However, these investigations have concentrated on femoral morphology, with limited attention given to tibial morphology. Moreover, the measurements obtained in these studies have been limited in scope and have primarily pertained to joint orientation angles [65,70]. A single study employing CT has explored bone deformities associated with MPL in Toy Poodles and demonstrated CT's reduced susceptibility to potential artifacts and rotational deformities of the tibia [6].

Currently, a greater body of evidence exists concerning the morphometric characteristics of the tibia in relation to cruciate disease. For example, a study discovered a potential elevated risk of caudal cruciate injury in Bassett hounds with an increased cranial to caudal width of the tibial tuberosity [71]. Additionally, a previous report demonstrated a strong correlation between a smaller relative tibial tuberosity width (rTTW) and the development of cranial cruciate ligament disease [72]. This indicates that a decreased rTTW may lead to a shift in tibial thrust force [72]. In the context of dynamic stabilization of cruciate ligament insufficient stifles, cranialization of the tibial tuberosity plays a pivotal role in neutralizing tibiofemoral shear forces through modification of the patellar ligament vector [47].

At present, the relationship between tibial tuberosity size and MPL remains uncertain, supporting further investigation. To the best of our knowledge, no morphometric studies have explored the width of the tibial tuberosity in terms of its potential association with MPL across various breeds and patient sizes. Comparative data comparing clinical and experimental cases are currently lacking, thus precluding the establishment of the superiority of cranialization and lateralization of the tibial tuberosity over a more traditional lateralization only approach.

5.2 Study limitations

This study had several limitations. Firstly, its retrospective design relied on the accuracy and completeness of clinical records, particularly regarding surgical approach, complications, and procedures performed. The variability in the chosen corrective approaches, driven by surgeon preference due to the lack of a standardized protocol, introduced potential confounding factors. The follow-up period was limited to a minimum of 6-8 weeks, which may not capture longer-term complications. Only incisional healing and bone healing were evaluated during this period, with no comprehensive assessment of overall clinical outcomes. Validated owner-reported outcome measures (OROMs) could provide valuable data but may underestimate late-onset complications. Reviewers of the radiographs were not blinded to the surgical procedures, which could introduce bias based on surgeon preference. Interobserver variability was assessed to mitigate this bias. The statistical analysis focused on the rate of complication development rather than the simple proportion of events. Therefore, further follow-up evaluation is warranted to investigate the outcomes generated in this study.

5.3 Conclusion

In conclusion, these results indicated an association between osteotomy segment size and complications in dogs undergoing TTT for MPL. It is recommended to consider osteotomy ratios of 1-1.19 times the diameter of the mid tibial diaphysis as an optimal size based on preoperative radiographic measurements. Additionally, addressing the trochlear groove during surgery appeared to have a protective effect in reducing post-operative complications. However, it is important to note that these findings are limited by the retrospective nature of the study. Further prospective evaluation of outcomes and mechanical testing should be conducted to validate these findings and provide more robust evidence.

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ADDENDUMS

Appendix A: University of Pretoria Animal Ethics Approval Certificate

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Veterinary Science
Animal Ethics Committee

06 June 2023

Approval Certificate
Amendment 2

AEC Reference No.: REC144-21 Line 4
Title: Retrospective assessment of the tibial tuberosity osteotomy location on the postoperative complications in dogs surgically treated for medial patella luxation
Researcher: Dr PD Guy
Student's Supervisor: Dr AM Kitshoff

Dear Dr PD Guy,

The **Amendment** as supported by documents received between 2023-04-20 and 2023-05-29 for your research, was approved by the Animal Ethics Committee on its quorate meeting of 2023-05-29.

Please note the following about your ethics approval:

1. **The change in title is approved:** Retrospective assessment of the tibial tuberosity osteotomy location on the postoperative complications in dogs surgically treated for medial patella (new)

   (old) A Preventative approach to the treatment of patella luxation in skeletally immature dogs

   The change in the Research Team is approved: Addition of a co-worker Dr Christelle Le Roux. Registered small animal radiologist

   The change in Methodology is approved:

   Medical records and radiographs of 89 dogs (109 limbs) that presented to OVAH, Faculty of Veterinary Science, with a diagnosis and treatment of MPL.
   Inclusion criteria
   - Animals with a diagnosis of congenital MPL confirmed on physical examination and radiographic findings that underwent a tibial tuberosity transposition.
   - Preoperative, post-operative and follow up radiographs, showing clinical union of the osteotomy
   - Detailed surgical reports
   - Post-operative treatment
   - Descriptions for any treatments given for complications

   Exclusion criteria
   - Suspected traumatic patella luxation
   - Patients with bidirectional patella luxations
   - Patients having a distal femoral osteotomy and not a tibial crest transposition
   - Concurrent orthopedic disease (Cranial cruciate ligament rupture)
   - Neurological abnormalities
   - Previous surgery on affected pelvic limb

   Medical records will be searched to identify dogs that had undergone surgical treatment for medial patella luxation between 2015 and 2021. Dogs will be excluded from the study as above

   Complications
   Data from follow up orthopedic and radiographic assessment at 6-8 weeks, or if the patient presented sooner with complications will be assessed. All follow up data will be assessed following any additional medical or surgical treatment until the point when the complication resolved.

Room 6-13, Arnold Theiler Building, Onderstepoort
Private Bag X04, Onderstepoort 0110, South Africa
Tel +27 12 529 8434
Fax +27 12 529 8321
Email: marleze.rheeder@up.ac.za

Fakulteit Veeartsenykunde
Lefapha la Disaense tša Bongakadiruiwa

2. Please note that the approved date(s) from the original application certificate / annual renewal certificate will be applicable to this amendment.

3. Please remember to use your protocol number (REC144-21) on any documents or correspondence with the AEC regarding your research.

4. Please note that the AEC may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

5. **All incidents** must be reported by the PI by email to Ms Marleze Rheeder (AEC Coordinator) within 3 days, and must be subsequently submitted electronically on the application system within 14 days.

6. The committee also requests that you record major procedures undertaken during your study for own-archiving, using any available digital recording system that captures in adequate quality, as it may be required if the committee needs to evaluate a complaint. However, if the committee has monitored the procedure previously or if it is generally can be considered routine, such recording will not be required.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Prof V Naidoo
CHAIRMAN: UP-Animal Ethics Committee

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Fakulteit Veeartsenykunde
Lefapha la Disaense tša Bongakadiruiwa

Appendix B: Section 21

agriculture, land reform & rural development

Department:
Agriculture, Land Reform and Rural Development
REPUBLIC OF SOUTH AFRICA

Directorate Animal Health, Department of Agriculture, Land Reform and Rural Development
Private Bag X138, Pretoria 0001

Enquiries: Ms Marna Laing • Tel: +27 12 319 7442 • Fax: +27 12 319 7470 • E-mail: MarnaL@dalrrd.gov.za
Reference: 12/11/1/1/8 (4015 SdIR)

Responsible person: Dr Peter Guy
Institution: Onderstepoort Veterinary Academic Hospital
Soutpan Road
Onderstepoort, Pretoria
Email: peterguyvet@gmail.com

Dear Dr Peter Guy,

PERMISSION TO DO RESEARCH IN TERMS OF SECTION 20 OF THE ANIMAL DISEASES ACT, 1984 (ACT NO 35 OF 1984)

Title of research project / study: "Retrospective assessment of tibial tuberosity osteotomy location on the postoperative complications in dogs surgically treated for medial patella luxation."

Your application dated 29/06/2023, requesting permission under Section 20 of the Animal Diseases Act, 1984 (Act No 35 of 1984) to perform the research project or study stipulated above, refers.

Based on the information provided in your application, your study does not fall under the scope of Section 20 of the Animal Diseases Act, 1984 (Act no 35 of 1984) provided that statements 1 to 8 hereunder (as applicable) are, and remain, accurate in relation to your research project.

Should the accuracy of any of the statements 1 to 8 hereunder change in any way in relation to your project, you are required to inform the Section 20 Secretariat. You may not proceed with any activities until written permission to do so have been granted by the National Director of Animal Health.

1. No work will be done with any controlled and/or notifiable animal diseases (list of diseases can be obtained from this office), which also includes any animal diseases which do not occur in South Africa;
2. No work will be done with any pathogen, disease, vector, micro-organism, parasite or animal material (including vaccine, serum, test kit, toxin, anti-toxin, antigen, biological product which consists or originates from a micro-organism, animal or parasite);
3. No imported material of animal origin or imported animal pathogens will be utilized in the study;
4. No samples that originate from a biobank will be used in the study;
5. No clinical studies will be performed in the target species, either in a laboratory or in the field;
6. The areas where the samples are to be collected are not under restriction for controlled or notifiable animal diseases to which the species of animal, from which the samples are obtained, is susceptible;
7. No samples or products will be obtained from an abattoir.
8. All biological or potentially infectious material must be packaged and transported in accordance with the International Air Transport Association (IATA) requirements and/or the National Road Traffic Act, 1996 (Act No. 93 of 1996).

Written permission from the Director of Animal Health must be obtained prior to any deviation from the conditions. Application must be sent in writing to MarnaL@dalrrd.gov.za Failure to obtain written permission as above may be considered a contravention of the Animal Diseases Act, 1984 (Act no 35 of 1984).

Kind regards,

pp.

Dr Mpho Maja
DIRECTOR: ANIMAL HEALTH
Date: 2023 07 03