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Patella tendinopathy Zoobiquity — What can we learn from dogs?☆

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ABSTRACT

Background: Patella tendinopathy is an overuse condition. Pathogenesis and identification of intrinsic risk factors have largely eluded the orthopaedic world. The cranial cruciate ligament (CrCL) in dogs is the equivalent to the human anterior cruciate ligament (ACL). We report the effect of two canine proximal tibial osteotomy procedures in the veterinary literature on patella tendon moment arm and describe the biomechanical rationale for a tibial tubercle osteotomy for treatment of patella tendinopathy in the human.
Methods: A literature review of studies reporting clinical complications of TTA and TPLO to form an observational animal cohort study in dogs.
Results: The veterinary literature reports an overall clinical complication rate of up to 61% for TTA and up to 50% for TPLO respectively. Complications associated with the extensor mechanism of the knee are <1% for TTA compared to 1.9–19% for TPLO. Radiographic thickening of the patella tendon and tendinopathy is seen in one to 80% of TPLO cases. The TPLO decreases the moment arm of the extensor mechanism meaning increased force is required in the patella tendon to achieve the same torque when compared to the TTA which increases the efficiency of the extensor mechanism. This difference may account, in part, for the post-operative complications reported to the patella and patella tendon following TPLO.
Conclusion: This observational animal cohort study demonstrates a biomechanical rationale for investigating diagnostic and potential treatment options, including a tibial tubercle osteotomy, for patella tendinopathy in humans based on this principle.

1. Introduction

Patella tendinopathy is an overuse condition most commonly affecting jumping athletes, with a reported incidence of greater than 50% for volleyball and basketball players and an overall incidence of 14% [1]. Patella tendinopathy is characterised by pain and tenderness at the distal pole of the patella [2]. There is a 53% incidence of retirement due to patella tendinopathy *vs* seven percent of other athletes retiring due to injury [3].

Risk factors for the condition are either extrinsic that are external to the athlete or intrinsic which are internal to the athlete. Extrinsic risk factors include increased training volume and harder training surfaces [4–6]. Intrinsic risk factors include hamstring and muscle tightness [7], abnormal leg lengths and loss of medial arch of the foot [5]. Previous studies have failed to show a statistical difference in the morphology of the patella of those with and without patella tendinopathy [8,9,4]. These studies have ex-

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amined the patella for differences in anatomy based on radiographic risk factors associated with patellofemoral pain and dislocation. Kujala et al. [10] found differences in the patella height of those with patella tendinopathy and Tscholl et al. [11] again found differences regarding patella height, tilt and tibial tubercle trochlea groove distance. However these mean differences were still largely within the range of quoted normal values for these measures, suggesting we need to redefine how we view abnormalities of the extensor mechanism related to patella tendinopathy.

There are a multitude of treatments for patella tendinopathy [12]. Surgery is performed on the premise of replacing a 'bad scar' with 'good scar' [13]. There is no proven benefit to surgery with high level evidence [14]. Multiple treatments combined with ongoing patient morbidity reflects that none of these treatments are truly effective.

We have proposed that the answer to identifying patella based intrinsic risk factors and improving treatment lies in addressing the biomechanics of the extensor mechanism through a tibial tubercle osteotomy [15]. The patella's role in the extensor mechanism is to increase the moment arm of the knee [16] and act as a lever to change the patella and quadriceps force vector through flexion [17]. We have demonstrated differences in the patella's lever arm in a radiographic case control series in those with patella tendinopathy compared to normal subjects [18].

Animal models for patella tendinopathy are not inducive to exploring these biomechanical risk factors and treatment. Animal models for patella tendinopathy can be induced mechanically by repetitive loading causing micro trauma to the tendon or chemically by collagenase injection. These models are limited in that the condition can self-resolve and they are performed in small animals with significant gait differences to humans, namely walking or hoping with a flexed knee [19,20,21].

Zoobiquity is the term used to describe the collaboration between the human and veterinary professions in order advance scientific understanding in both fields [22]. Zoobiquity is based on the assumption that humans and animals share commonalities with respect to the pathogenesis of disease; synonymous with the One Health Initiative [23]. It's role in orthopaedics and dogs has recently been explored with hip dysplasia [24].

The cranial cruciate ligament (CrCL) is the canine equivalent of the human anterior cruciate ligament (ACL). CrCL rupture is one of the most common causes of lameness in dogs [25]. Surgical intervention is preferred over conservative management to re-establish joint stability, mitigate secondary degenerative joint disease, and address any concurrent meniscal injury [26,27]. Although debate continues over which is better, tibial plateau levelling osteotomy (TPLO) and tibial tuberosity advancement (TTA) are two commonly performed proximal tibial osteotomies that stabilise the CrCL deficient stifle joint by neutralising tibiofemoral shear forces [28]. Patella tendinopathy (also known as tendinitis or desmitis in the veterinary literature) is a rare clinical form of lameness on its own in dogs, but is commonly reported post-operatively following TPLO [29,30]. Comparatively, TTA is typically not associated with patella tendinopathy [28].

In this paper, our aim was to explore the complications following the TPLO and TTA procedures in dogs, summarising these complications in relation to development of patella tendinopathy. In the discussion we will explore the biomechanical principles of the knee joint, specifically the patella tendon. In addition, we describe the relevance of such knowledge in the management and treatment of patella tendinopathy in humans.

2. Methods

A literature review was performed with PubMed using MeSH terms "dog" AND "cranial cruciate" AND "osteotomy" AND "complication" which generated 123 results. We screened abstracts and full texts and included studies which related to TTA and/or TPLO and included a quantitative description of the complications of each group. A total of 28 studies were found and grouped by the osteotomy type to allow for an observational cohort study based on the osteotomy for comparison of complications.

We grouped studies which reported on both clinical and radiographic patella tendinopathy to provide a non-weighted group summary of studies that reported on extensor mechanism complications. The studies included were of low level evidence, as such no meta-analysis was performed [31].

Patella tendinopathy was defined as reported by the authors, clinically or radiologically, using the terms 'tendinopathy', 'tendinitis' or 'desmitis'.

3. Results

Tables 1 and 2 list the 28 studies obtained following literature review. Studies are described by study design, number of procedures, mean dog age and weight with standard deviation when reported. The majority of studies are retrospective, involve medium to large breed dogs aged between four and six years of age.

Tables 3 and 4 provide an individual breakdown of the complications reported for both procedures. There was an overall complication rate of and 7.2–50% and 11.3–34% for TTA and TPLO respectively. Where cells are left blank it means the paper did not specifically report that complication.

Table 5 provides a non-weighted group summary of studies that reported on both clinical and radiographic patella tendinopathy. Patella tendinopathy is rarely reported following TTA but has a radiographic incidence of 19%, associated lameness of 5.9% and tendon rupture or patella fracture of 10.7% following TPLO. We considered tibial tuberosity fracture to be a complication relating directly to the osteotomy of the TTA and not altered biomechanics so it was not included in Table 5.

Table 1
Summary of retrospective and prospective studies where standard and modified tibial tuberosity advancement (TTA) was performed.

Study	Study design	Number of procedures	Age (years)	Body weight (kg)
Hoffmann et al., 2006 [32]	Retrospective	65	5.2 ± 2.5	39.7 ± 11.9
Stein & Schmoekel, 2008 [33]	Retrospective	70	4.6	N/A
Steinberg et al., 2011 [34]	Retrospective	193	5.5	38.5
Hirshenson et al., 2012 [35]	Retrospective	101	4.5	39.1
Wolf et al., 2012 [36]	Retrospective	501	5.44	34.4
Christopher & Cook, 2013 [37]	Retrospective	18	5.05	40.2
Pettit et al., 2014 [38]	Prospective	25	4.7	36.8
Ramirez et al., 2015 [39]	Retrospective	84	5.1 ± 2.6	28 ± 13
Butterworth et al., 2017 [40]	Retrospective	152	5.96	27.7
Lafaver et al., 2007 [41]	Retrospective	114	5.9	36.7
Ferreira et al., 2016 [42]	Prospective	12	4.8 ± 1.9	35.5 ± 8.5
DeSandre-Robinson et al., 2017 [43]	Retrospective	47	5.6 ± 2.6	33.0 ± 7.8
Hans et al., 2017 [44]	Retrospective	91	5.0 ± 2.2	55.4
Lefebvre et al., 2018 [45]	Retrospective	174	6	28.8

Age and weight of dogs in these studies are reported as mean ± standard deviation (SD).

4. Discussion

4.1. Clinical aspects in dogs

Patella tendinopathy in dogs is largely observed as thickening of the patella tendon on imaging modalities such as radiography and ultrasound [29]. Radiographic findings include thickening of the distal patella tendon, as opposed to the proximal part of the tendon in humans, demonstrated in Figure 1. Ultrasound findings are similar to the human with thickening and heterogeneity of the echogenicity of the tendon. Clinical lameness due to patella tendinopathy is much less than the incidence of tendon thickening on radiography [29]. This lameness largely resolves with time or physiotherapy but occasionally results in patella tendon rupture or patella fracture.

There is emerging literature from Pettit et al. [38] and DeSandre-Robinson et al. [43] of an increasing incidence of patella tendon thickening with TTA. These studies are in contrast to the majority of the reported literature as outlined in Table 3. No associated clinical problems with the extensor mechanism have been noted. Therefore, it remains that patella tendinopathy is not associated with TTA.

4.2. Aetiology

While some studies suggest the difference in extensor mechanism related complications between TTA and TPLO could be attributed to non-biomechanical factors, these are hard to support. Pacchiana et al. [47] and Carey et al. [30] propose that patella tendinopathy may be due to differences in the post operative activity of dogs and/or intra-operative disruption to the blood supply of the patella tendon. It is difficult if not impossible to standardise post operative activity in this animal cohort or enforce strict owner compliance. We do not see how post-operative activity levels could be attributed to complications of the procedure itself.

Table 2
Summary of studies where tibial plateau levelling osteotomy (TPLO) was performed.

Study	Study design	Number of procedures	Age (years)	Body weight (kg)
Barnhart et al., 2003 [46]	Retrospective	25	4.9	36.1
Pacchiana et al., 2003 [47]	Retrospective	397	5.0 ± 0.1	39.9 ± 0.6
Priddy et al., 2003 [48]	Retrospective	253	4.7 ± 2.1	41.2 ± 11.7
Carey et al., 2005 [30]	Retrospective	94	5 ± 2.5	36.8 ± 11.5
Stauffer et al., 2006 [49]	Retrospective	696	6.2	38.4
Corr et al., 2007 [50]	Retrospective	21	3.9 ± 1.8	47.9 ± 16.5
Conkling et al., 2010 [51]	Prospective	118	5.7	41.7
Cook et al., 2010 [52]	Prospective	23	5.7 ± 2.5	38.8 ± 16.3
Fitzpatrick & Solano, 2010 [53]	Retrospective	1146	5.6	32
Gatineau et al., 2011 [54]	Retrospective	476	5	36
Christopher & Cook 2013 [37]	Retrospective	65	4.76	38.4
Coletti et al., 2014 [55]	Retrospective	1519	5.4 ± 2.6	37.3 ± 11.0
Witte et al., 2014 [56]	Retrospective	29	5.4 ± 2.7	9.2 ± 2.5
Barnes et al., 2016 [57]	Retrospective	26	7	10.3
Ferreira et al., 2016 [42]	Retrospective	15	4.4 ± 1.9	34.9 ± 11.1
DeSandre-Robinson et al. 2017 [43]	Retrospective	59	4.4 ± 2.3	33.1 ± 10.9
Hans et al., 2017 [44]	Retrospective	54	4.4 ± 2.3	59.6
Knight & Danielski, 2018 [58]	Retrospective	66	6.4 ± 2.7	9.5 ± 1.9

Age and weight of dogs in these studies are reported as mean ± standard deviation (SD).

Table 3
Summary of postoperative complications reported in prospective and retrospective studies following tibial tuberosity advancement (TTA) in dogs.

	Hoffmann et al., 2006 [32]	Lafaver et al., 2007 [41]	Stein & Schmoekel, 2008 [33]	Steinberg et al., 2011 [34]	Hirshenson et al., 2012 [35]	Wolf et al., 2012 [36]	Christopher & Cook, 2013 [37]	Pettit et al., 2014 [38]	Ferreira et al., 2016 [42]	Ramirez et al., 2016 [39]	Butterworth et al., 2017 [40]	DeSandre-Robinson et al., 2017 [43]	Hans et al., 2017 [44]	Lefebvre et al., 2013
Number of procedures	65	114	70	193	101	501	18	25	12	84	152	47	91	174
Surgical wound[a]	19	7	2	5	6	33	4		2	2			8	
Infection		3		1	1					1			14	
Intraoperative[b]	2	3				2			1	26	3			70
Implants[c]	1	3		2	1	10				1			1	
Repeat surgery performed			10			33								
Medial patella luxation	1	1		1	1									
Delayed union/non--union														
Medial meniscal injury	3	7	6	10	5	19	5			3				
Stifle instability/-pivot shift			2											
Fibula head fracture														
Other/not classified		8			4		2			6				
Extensor mechanism complications														
Patella tendon thickening		1				2		12				43	1	
Patella tendonitis		1												
Patella fracture														
Patella tendon rupture														
Tibial tuberosity fracture		4	3	2	2	21				1			8	21
Total number of complications	26 (27)	36 (36)	23 (12)	21 (21)	20 (20)	120 (95)	11 (11)	12	3	40 (43)	3 (11)	43 (43)	32 (31)	91

Note discrepancy in total complications that we tallied from the listed individual complications compared with the cumulative total reported by authors in brackets.
[a] Surgical wound complications include; wound dehiscence, seroma formation etc.
[b] Intraoperative complications include; haemorrhage, broken drill bit, damage to medial tibial cortex, intra-articular screw placement etc.
[c] Implant complications include; screw/plate/Kirshner wire loosening, breakage, failure etc.

Table 4
Summary of postoperative complications reported in prospective and retrospective studies following standard tibial plateau levelling osteotomy (TPLO) in dogs.

	Barnhart et al., 2003 [46]	Pacchiana et al., 2003 [47]	Priddy et al., 2003 [48]	Carey et al., 2005 [30]	Stauffer et al., 2006 [49]	Corr et al., 2007 [50]	Conkling et al., 2010 [51]	Cook et al., 2010 [52]	Fitzpatrick & Solano, 2010 [53]	Gatineau et al., 2011 [54]	Christopher & Cook, 2013 [37]	Coletti et al., 2014 [55]	Witte et al., 2014 [56]	Barnes et al., 2016 [57]	Ferreira et al., 2016 [42]	DeSandre-Robinson et al., 2017 [43]	Hans et al., 2017 [44]	Knight & Danielski, 2018 [58]
Number of procedures	25	397	253	94	696	21	118	23	1146	476	65	1519	29	26	26	59	54	66
Surgical wound[a]	5	17			51	1	4	4	10		6	47			1		9	9
Infection		10	25			3	1	1	66	14		9	1				14	
Intraoperative[b]		3	23		6										3			
Implants[c]		6	6		6	2	1	2	4	11			3				2	
Revision surgery performed		19				1			26	5		44						
Medial patella luxation									3			13						
Delayed union/non--union							6		3									
Medial meniscal injury		4		2				1	56	10	8	12						
Stifle instability/-pivot shift							1		4	14		1						2
Fibula head fracture			9		5	2			1	2					1		2	
Other/not classified			3		16				72		1							4
Extensor mechanism complications																		
Patella tendon thickening		19		75	19			1	3			5		14		57		
Patella tendonitis		2		24			1							1				
Patella fracture		1		1					1	1								
Patella tendon rupture									4									
Tibial tuberosity fracture		14	6	4	28	1	2		5			53						
Total number of complications	5 (5)	95 (136) 23.92%	35 (66)	106	131 (131)	10 (9) 47.62%	16 (22)	9 (9)	258 (148)	57 (57)	15 (18)	184 (173)	4 (4)	15 (26)	5	57	27 (27) 50%	15 (15)

Note discrepancy in total complications that we tallied from the listed individual complications compared with the cumulative total reported by authors in brackets.
[a] Surgical wound complications include; wound dehiscence, seroma formation etc.
[b] Intraoperative complications include; haemorrhage, broken drill bit, damage to medial tibial cortex, intra-articular screw placement etc.
[c] Implant complications include; screw/plate/Kirshner wire loosening, breakage, failure etc.

Table 5
Complications of the extensor mechanism for tibial tuberosity advancement (TTA) and tibial plateau levelling osteotomy (TPLO) procedures.

Extensor mechanism complications	TTA [41][a]	TPLO [47,48,30,49,52,53,57][a]
Patella tendon thickening	1 (<1%)	94 (19%)
Patella tendinitis (clinical)	1 (<1%)	29 (5.9%)
Patella fracture		22 (1.9%)
Patella tendon rupture		61 (8.8%)

[a] Only those studies that individually reported both radiographic thickening and clinical tendinopathy were included.

Further, Johnson et al. [59] examined the effect of TTA and TPLO cadaveric procedures on the blood supply to the patella tendon and found both procedures disrupt the same vasculature due the requirement for knee arthrotomy, however this does not preclude the possible aetiology of scarring associated with violation of the fat pad with the TPLO (Figure 2).

Boudrieau [28] explored the biomechanical differences between TTA and TPLO. Torque is a rotational force that it is equal to the moment arm (perpendicular distance from the force vector to the point of rotation) multiplied by the force vector. In a TTA, the moment arm is increased. Therefore, to achieve the same extension torque, less force is required through the patella tendon. Conversely, TPLO which is the point of rotation on the femur is brought anterior relative to the tibia, which decreases the relative moment arm. Therefore, to achieve the same torque, a larger amount of force is exerted through the patella tendon. It is this increased force/load that may explain the higher incidence of patella tendinopathy following TPLO. Comparatively, TTA may have a protective effect on the patella tendon due to the decreased force exerted while maintaining the efficiency in torque. See Figure 1 for a visual demonstration of this concept.

This concept is in agreeance with the human cadaveric work by Kaufer [16] and Maquet [60] which established the moment arm role of the patella and the utility of anteriorisation of the tibial tubercle. Lewallen et al. [61] also demonstrated a trend for the force through the patella tendon to decrease with anteriorisation of the patella tendon for 30–60 degrees of knee flexion.

The veterinary literature is not consistent on patella tendon forces in CrCL deficient dogs following TPLO and TTA. Drew et al. [62] claimed to show no difference in the stifle extensor mechanism following TPLO of CrCL in-tact stifles of canine cadavers. However, they applied and measured the force at the patella (bone) and claimed it represented the patella tendon force. This assumes the extensor mechanism is a pulley, which is inaccurate as it fails to take into account the lever role of the patella with the changing patella tendon to quadriceps tendon force ratio based on the amount of knee flexion [17]. Comparatively another study has shown the TPLO does lower the force required to fracture the patella with an applied quadriceps load [63], supporting the theory that the decreased moment arm of TPLO increases the forces through the extensor mechanism.

4.3. Relevance to humans

There are different aetiologies attributed to patella tendinopathy. We have explored this in greater detail previously [15], suffice to say we concede that there is debate over the aetiology of patella tendinopathy as a stress shielding/compressive phenomenon [1,2] *vs* a repetitive micro-overload pathogenesis. There appears to be sufficient clinical evidence to exclude compressive aetiology [16] and ample biomechanical cadaveric evidence and finite element models to support repetitive micro-overload

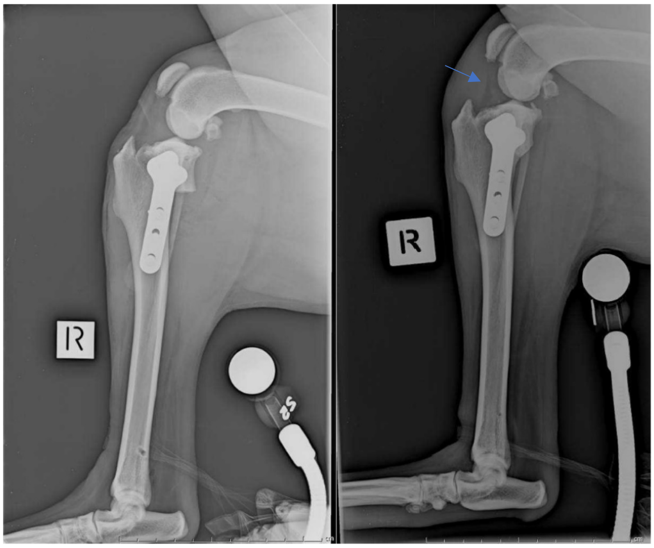

Figure 1. Patella tendon thickening post TPLO. The radiograph on the left was taken immediately post-operatively showing the normal outline of the patella tendon. The radiograph on the right was taken 6 weeks post-operatively and demonstrates thickening of the distal portion of the patella tendon (arrow).

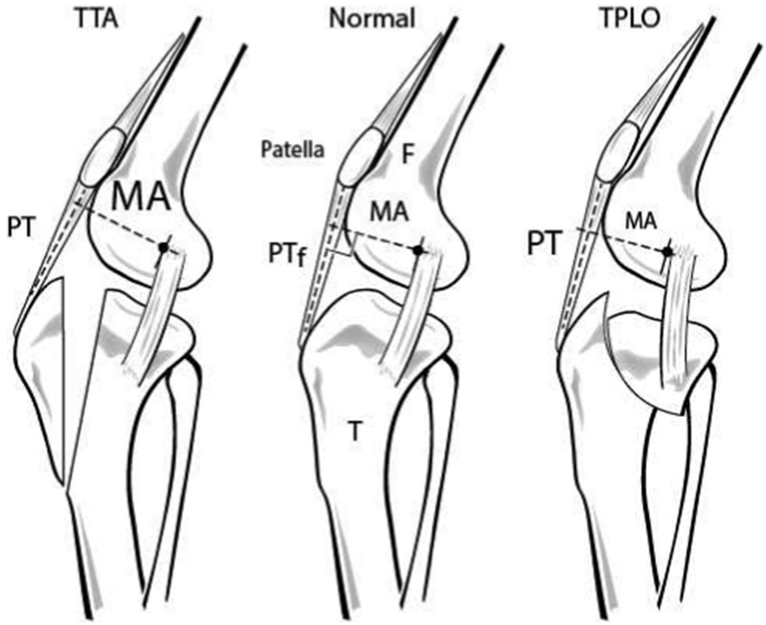

Figure 2. Moment arm differences following tibial tuberosity advancement (TTA) and tibial plateau levelling osteotomy (TPLO). Following TTA, the moment arm (MA) is increased; therefore, to achieve the same extension torque, less force is required through the patella tendon (PT). Conversely, following TPLO, the point of rotation is changed and as a result the moment arm of the PT is shortened. Therefore, to achieve the same torque, a larger amount of force is exerted through the patella tendon. Note: differences in PT magnitude are reflected by font size. T = tibia, F = femur.

[3,8,12]. The repetitive micro-overload theory is in keeping with the known overload extrinsic risk factors from clinical studies [6,18,22]. Numerous papers have failed to identify patella based intrinsic risk factors as they have tried to associate known pathological anatomies of patellofemoral pain and dislocation with tendinopathy, not biomechanical aspects of the extensor mechanism [8,9,4].

The patella has two roles; 1) as a lever and 2) to increase the moment arm of the extensor mechanism. We believe, in agreeance with Tscholl et al. [11], the answer to treating patella tendinopathy lies in altering the biomechanics of the extensor mechanism to be more favourable to the patella tendon [15]. Based on the work of Huberti et al. [17], identifying the patella as a lever in the sagittal plane, the patella tendon force is not 1:1 with the quadriceps tendon force. The ratio changes based on the lever arm generated due to whether the proximal or distal pole of the patella is articulating with the femur. We identified a shorter patella tendon lever arm as an intrinsic risk factor associated with the development of patella tendinopathy [18]. This signifies that those with patella tendinopathy will experience greater force through their patella tendon compared to those without due to the relationship of their patella relative to the femur. A distalizing tibial tubercle osteotomy will alter the point of articulation of the patella on the femur, moving it proximally on the patella earlier in the knee flexion range. This change in the articulation point/pivot point/fulcrum of the patella will manipulate the patella tendon to quadriceps tendon force ratio to decrease the force through the patella tendon and relatively increase the force through the quadriceps tendon earlier in the knee range of motion, the range associated with running, jumping and landing [64].

Previous study investigating moment arm characteristics as an intrinsic risk factor for patella tendinopathy in humans remain unreported. This animal model provides rationale for an anteriorising tibial tubercle osteotomy. As identified by Kaufer [16] and Maquet [60], by anteriorising the tibial tubercle the force required through the extensor mechanism to achieve the same amount of torque through the knee will be decreased. This offers a potential biomechanical solution to patella tendinopathy.

Further biomechanical work is needed to quantify the effect of different tibial tubercle positions on the patella tendon forces and to ensure the patellofemoral articular forces are not substantially increased before implementing clinically.

5. Conclusion

This observational animal cohort study demonstrates the protective association of an increased patella tendon moment arm (TTA) and the detrimental effects of a decreased moment arm with the development of patella tendinopathy (TPLO) in dogs. This study supports the rationale for further clinical and cadaveric studies exploring the biomechanical and clinical outcomes of a tibial tubercle osteotomy as a biomechanical treatment for patella tendinopathy.

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