การเปรียบเทียบมุมของกระดูกขาหลังของสุนัขพันธุ์ปอมเมอเรเนียนและพันธุ์ชิวาวา ที่มีข้อเข่าปกติและข้อเข่าที่มีสะบ้าเคลื่อนเข้าด้านในจากภาพเอกซเรย์ และภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์

นางสาวฐิตาภรณ์ เพ็ชรแก้ว

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A COMPARISON OF PELVIC LIMB ANGULAR VALUES OF POMERANIAN AND CHIHUAHUA DOGS WITH NORMAL AND MEDIAL PATELLAR LUXATION STIFLES USING RADIOGRAPHY AND COMPUTED TOMOGRAPHY

Miss Thitaporn Phetkaew

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By	Miss Thitaporn Phetkaew
Field of Study	Veterinary Surgery
Thesis Advisor	Assistant Professor Chalika Wangdee, D.V.M., M.Sc., Ph.D., D.T.B.V.S.
Thesis Co-Advisor	Professor Marissak Kalpravidh, D.V.M., M.S., Ph.D., D.T.B.V.S.

Accepted by the Faculty of Veterinary Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

---Dean of the Faculty of Veterinary Science

(Professor Roongroje Thanawongnuwech, D.V.M., M.S., Ph.D., D.T.B.V.P.)

THESIS COMMITTEE

---Chairman

(Assistant Professor Sumit Durongphongtorn, D.V.M., DVSc.,D.T.B.V.S.)

---Thesis Advisor

(Assistant Professor Chalika Wangdee, D.V.M., M.Sc., Ph.D., D.T.B.V.S.)

---Thesis Co-Advisor

(Professor Marissak Kalpravidh, D.V.M., M.S., Ph.D., D.T.B.V.S.)

---Examiner

(Assistant Professor Sayamon Srisuwatanasagul, D.V.M., M.Sc., Ph.D.)

---External Examiner

(Assistant Professor Monchanok Vijarnsorn, D.V.M., M.Sc., Ph.D., D.T.B.V.S.)

ฐิตาภรณ์ เพ็ชรแก้ว : การเปรียบเทียบมุมของกระดูกขาหลังของสุนัขพันธุ์ปอมเมอเรเนียนและพันธุ์ชิวาวาที่มีข้อเข่าปกติและข้อเข่าที่มีสะบ้าเคลื่อนเข้าด้านในจากภาพเอกซเรย์และภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์ (A COMPARISON OF PELVIC LIMB ANGULAR VALUES OF POMERANIAN AND CHIHUAHUA DOGS WITH NORMAL AND MEDIAL PATELLAR LUXATION STIFLES USING RADIOGRAPHY AND COMPUTED TOMOGRAPHY) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. สพ.ญ. ดร. ชาลิกา หวังดี, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ศ. น.สพ. ดร. มาริษศักร์ กัลล์ประวิทธ์, 51 หน้า.

การศึกษาเปรียบเทียบค่ามุมกระดูกต้นขาและกระดูกหน้าแข้ง ในสุนัขพันธุ์ชิวาวาและปอมเมอเรเนียนที่มีข้อเข่าปกติและข้อเข่าที่มีสะบ้าเคลื่อนเข้าด้านใน โดยใช้เทคนิคเอกซเรย์และภาพถ่ายรังสีส่วนตัดอาศัยคอมพิวเตอร์ เพื่อหาความสัมพันธ์ระหว่างมุมกระดูกขาหลังและการเกิดสะบ้าเคลื่อนเข้าด้านใน และหาวิธีการที่เหมาะสมในการประเมินภาวะผิดรูปของกระดูกดังกล่าว ในสุนัขพันธุ์ชิวาวาจำนวน 30 ตัว (60 ขาหลัง) และปอมเมอเรเนียน 36 ตัว (60 ขาหลัง) โดยถ่ายภาพเอกซเรย์และภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์ ในระนาบแบ่งหน้าหลัง เพื่อวัดมุม anatomical และ mechanical lateral proximal femoral angles (aLPFA และ mLPFA), anatomical และ mechanical lateral distal femoral angles (aLDFA และ mLDFA), inclination angle (ICA), mechanical medial proximal และ distal tibial angles (mMPTA และ mMDTA) ในระนาบแบ่งซ้ายขวาเพื่อวัดมุม precurvation angle (PA), anatomical caudal proximal และ distal femoral angles (aCdPFA และ aCdDFA), mechanical caudal proximal tibial angle (mCdPTA) และ mechanical cranial distal tibial angle (mCrDTA) และในระนาบแบ่งบนล่างเพื่อวัดมุม femoral และ tibial torsion angles (FTA และ TTA) รายงานค่าต่างๆ เป็นค่าเฉลี่ยและส่วนเบี่ยงเบนมาตรฐาน เปรียบในแต่ละวิธีการและแต่ละเกรด พบว่าในสุนัขพันธุ์ชิวาวามีความแตกต่างอย่างมีนัยสำคัญระหว่างเทคนิคทั้งสองแบบในกลุ่มข้อเข่าปกติคือ aLPFA, mLPFA, mMPTA, PA, aCdPFA และ aCdDFA ($p \le 0.05$). มุมที่มีความสัมพันธ์กับภาวะสะบ้าเคลื่อนเข้าด้านในจากภาพถ่ายรังสีส่วนตัดอาศัยคอมพิวเตอร์คือ aLDFA, mLDFA, mMPTA, FTA และ TTA ส่วนในสุนัขพันธ์ปอมเมอเรเนียน มุมที่มีความแตกต่างระหว่างระหว่างสองเทคนิคในกลุ่มข้อเข่าปกติคือ aLPFA, mLPFA, PA, และ aCdPFA ($p \le 0.05$) มุมที่มีความสัมพันธ์กับภาวะสะบ้าเคลื่อนเข้าด้านในจากภาพถ่ายรังสีส่วนตัดอาศัยคอมพิวเตอร์คือ aLDFA, mLDFA, และ FTA การศึกษานี้รายงานค่ามุมปกติของกระดูกขาหลังในสุนัขทั้งสองพันธุ์ และพบว่าค่ามุมที่ได้จากการถ่ายภาพเอกซเรย์มีข้อจำกัด ดังนั้นรายที่สงสัยมีการผิดรูปของกระดูกขาหลัง ควรใช้ภาพถ่ายรังสีส่วนตัดอาศัยคอมพิวเตอร์ในการประเมินด้วย

ภาควิชา	ศัลยศาสตร์	ลายมือชื่อนิสิต	....
สาขาวิชา	ศัลยศาสตร์ทางสัตวแพทย์	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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KEYWORDS: CHIHUAHUA, COMPUTED TOMOGRAPHY, MEDIAL PATELLAR LUXATION, PELVIC LIMB DEFORMITY, POMERANIANS

THITAPORN PHETKAEW: A COMPARISON OF PELVIC LIMB ANGULAR VALUES OF POMERANIAN AND CHIHUAHUA DOGS WITH NORMAL AND MEDIAL PATELLAR LUXATION STIFLES USING RADIOGRAPHY AND COMPUTED TOMOGRAPHY. ADVISOR: ASST. PROF. CHALIKA WANGDEE, D.V.M., M.Sc., Ph.D., D.T.B.V.S., CO-ADVISOR: PROF. MARISSAK KALPRAVIDH, D.V.M., M.S., Ph.D., D.T.B.V.S., 51 pp.

Comparative study of angular values of femurs and tibias in Chihuahuas and Pomeranians with normal and MPL stifles by using radiography and CT scan was done to identify the angular values and relationship between pelvic limb angles and severity of MPL and to search for the suitable assessment method of limb deformity. Radiographic and CT scan images were obtained from 30 Chihuahuas (60 hind limbs) and 36 Pomeranians (60 hind limbs). In the frontal plane, anatomical and mechanical lateral proximal femoral angles (aLPFA and mLPFA), anatomical and mechanical lateral distal femoral angles (aLDFA and mLDFA), inclination angle (ICA), mechanical medial proximal and distal tibial angles (mMPTA and mMDTA) were evaluated. In the sagittal plane, precurvation angle (PA), anatomical caudal proximal and distal femoral angles (aCdPFA and aCdDFA), and mechanical caudal proximal tibial angle (mCdPTA) and mechanical cranial distal tibial angle (mCrDTA) were measured. In the transverse plane, femoral and tibial torsion angles (FTA and TTA) were evaluated. Means ± SD of all measured angles were reported and compared. In Chihuahuas, the significant differences of the measured values were found between those from radiography and CT scan including aLPFA, mLPFA, mMPTA, PA, aCdPFA, and aCdDFA in normal stifles ($p \leq 0.05$). From the CT scan, the angles related to severity of MPL were aLDFA, mLDFA, mMPTA, FTA and TTA. In Pomeranians, the significant differences of the measured values were found between those from radiography and CT scan including aLPFA, mLPFA, PA, and aCdPFA in normal stifles ($p \leq 0.05$). From the CT scan, the angles related to severity of MPL were aLDFA, mLDFA and FTA. This study reports the pelvic limbs goniometry values in both breeds and found limitation of the evaluation by radiography. Therefore, CT is recommended when the deformity is doubtful.

Department:	Veterinary Surgery	Student's Signature	....
Field of Study:	Veterinary Surgery	Advisor's Signature	....
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CHAPTER I
INTRODUCTION

Importance and rationale

Patellar luxation (PL) is a common orthopedic disease in dogs. Patella can be luxated to medial, lateral or both directions (Trotter, 1980; Hayes et al., 1994; Alam et al., 2007). Medial patellar luxation (MPL) is common in both small- and large-breed dogs. Whereas the small breeds show an over representation of PL and most cases are MPL (LaFond et al., 2002; Alam et al., 2007). The pathogenesis of PL has been substantially reported but the etiology still remains obscure (DeAngelis and Hohn, 1970; Hulse, 1981; Roush, 1993; Gibbons et al., 2006). The high susceptibility of PL in particular breeds; such as Pomeranian, Yorkshire Terrier, Miniature, Toy Poodle, Chihuahua, Boston Terrier, and Pekingese, together with an early age of onset, often with bilateral occurrence, gives a strong premise that PL is a genetic predisposition (Priester, 1972; Hulse, 1981; LaFond et al., 2002; Alam et al., 2007; OFA, 2015). PL is considered as a developmental condition causing anatomical abnormalities of the pelvic limb. There are several studies focusing on the skeletal abnormalities of the pelvic limb in large-breed dogs including malalignment of quadriceps mechanism, coxa vara, shallow trochlear groove with poorly developed trochlear ridge, femoral varus, internal rotation and torsion of the tibia (Hulse, 1993; Towle et al., 2005; Piermattei et al., 2006). However, a few studies observed these abnormalities in small-breed dogs and only few papers reported the abnormalities in particular breeds (Soparat et al., 2012; Yasukawa et al., 2016).

Skeletal deformities of MPL are more severe in the higher grades particularly femoral varus, internal tibial rotation and external tibial torsion. Although several surgical techniques of MPL have been described (DeAngelis and Hohn, 1970; Trotter, 1980; Willauer and Vaseur, 1987; Slocum and Slocum, 2000; Towle et al., 2005; Tomlinson et al., 2007), the recurrence still occurs (Willauer and Vaseur, 1987; Gibbons et al., 2006; Alam et al., 2007). Many studies have reported that an inadequate correction of femoral and/or tibial deformities could be a cause of postoperative recurrence of PL (Arthurs and Langley-Hobbs, 2006; Kowaleski, 2006; Fox and Tomlinson, 2012).

Many studies have focused on corrective osteotomy of femoral varus and external femoral torsion in severe MPL with pelvic limb malalignment (Bruecker, 2006; Persuki et al., 2006; Petazzoni, 2006; Roch and Gemmill, 2008). Accurate determination of the magnitude of conformational deformity is very important for surgical planning. However, the indications for surgery and normal reference values of limb angles in small-breed dogs have not been well defined. Assessment of angular limb deformity in dogs is mostly performed via radiography because of its widespread availability and low cost. However, this method requires precise radiographic positioning. In addition, three radiographic planes are necessary to obtain information on skeletal deformity. Recently, computed tomography (CT) image are used to assess limb deformity, because it is easier to perform and provides angular measurement more accurate than radiography. It is suggested to use this technique in dogs with severe limb deformity (Kowaleski, 2006). Nevertheless, CT scan is high cost and is not available in most practice services.

Lacking the supportive data of pelvic limb angular values in normal stifles of small-breed dogs, the criteria to correct limb deformities could not be drawn. This makes it difficult to treat severe MPL and to minimize complications after surgery in small-breed dogs.

This study scoped at Chihuahua and Pomeranian dogs because of high incidence of MPL in these two breeds (Hazewinkel et al., 2013; Soontornvipart et al., 2013; OFA, 2015). Angular values of femurs and tibias of the normal and the MPL stifles was reported and compared in order to identify the relationship between pelvic limb angles and severity of MPL. The angular values measured from the radiographic images and CT scan were compared to search for the suitable assessment method of limb deformity.

Objectives of the study

This study aimed to report and compare angular values of the hind limb in Pomeranian and in Chihuahua dogs with normal and MPL stifles using radiography and CT scan.

Research questions

1. What are the pelvic limb goniometry values measured from the radiographic images and by computed tomography of the Pomeranian and Chihuahua dogs with normal and MPL stifles?
2. Are pelvic limb angular values of dogs with MPL stifles different from the values of dogs with normal stifles?
3. Are the angular values measured from the radiographic image different from the values measured by computed tomography?

CHAPTER II
REVIEW OF LITERATURES

1. The prevalence of patellar luxation

Patellar luxation (PL) is one of the most common orthopedic diseases in dogs. Medial patellar luxation (MPL) is frequently found more than lateral patellar luxation (LPL), about 75-80% of cases (Hayes et al., 1994; Alam et al., 2007; Soontornvipart et al., 2013) (Figure 1). Small breed dogs represent high incidence of MPL which is more than 60% of all breeds (Gibbons et al., 2006; Alam et al., 2007; Wangdee et al., 2013). The high-risk breeds of MPL are Pomeranians, Yorkshire terrier, Chihuahuas and Poodles (LaFond et al., 2002; Alam et al., 2007; OFA, 2015). In Thailand, the prevalence of MPL in small-breed dogs is 87% and 75% of all PL affected dogs is Pomeranian. 86% is bilateral PL (Soontornvipart et al., 2013).

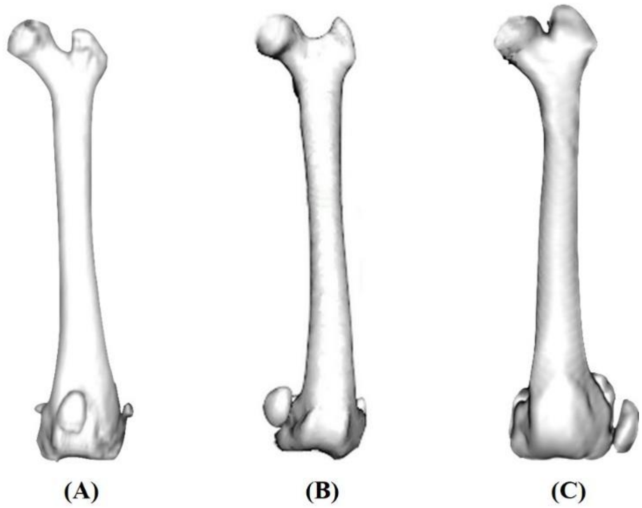


Figure 1 Normal and patellar luxation stifles.

(A) Normal stifle: patella sit in trochlear groove and femur is in normal alignment.

(B) Medial patellar luxation: patella luxate medially and distal femoral varus is noted.

(C) Lateral patellar luxation: patella luxate laterally and distal femoral valgus is noted

2. Pathophysiology of patellar luxation and limb deformities

The clinical sign of PL can be detected by palpation to examine if the patella slips medially, laterally or both directions from the trochlear ridge. PL is classified into 4 grades according to the classification by Singleton (Singleton, 1969). Grade 2 and 3 MPL are mostly observed in all breeds size (Hayes et al., 1994; Arthurs and LangleyHobbs, 2006; Gibbons et al., 2006; Alam et al., 2007). Grade 4 MPL is the most severe one with the deformities of involved structures noticed (Figure 2).

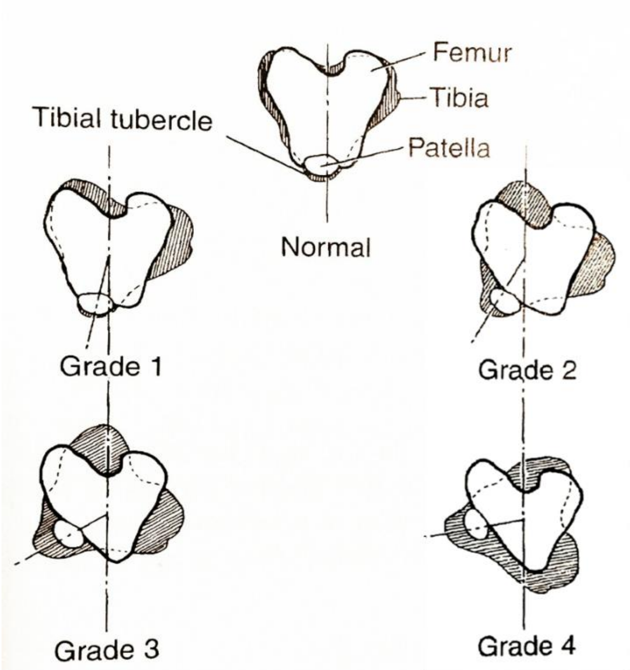


Figure 2 Position of tibia relative to the femur and shape of femoral trochlea in grades 1-4 MPL. The pictures are in cross section at level of femoral trochlea to proximal tibia. Progressive tibial medial rotation and trochlear ridge deformities are noted (Piermattei et al., 2006).

A heritable basis for the disease has been hypothesized which is supported by the predisposition of certain breeds together with the high prevalence of bilateral cases in the absence of trauma (Hayes et al., 1994; LaFond et al., 2002; Soontornvipart et al., 2013). The pathogenesis of MPL has been extensively reviewed; nonetheless, the etiology still remains controversial. Anatomic pelvic limb abnormalities have been hypothesized according to a theory from human literature. In the Hueter-Volkmann principle, immature dogs develop angular and torsional deformities due to abnormal force of quadriceps during luxation of patella against the active physis of femurs and tibias. The longer abnormal forces compress on open physis, the greater limb deformity and permanent luxation likely occurs (Hulse, 2011) (Figure 3). The skeletal deformities associated with MPL include abnormal conformation of coxofemoral joint, femoral varus angulation, medial deviation of tibial crest, quadriceps muscles malalignment and atrophy, rotational instability of the stifle joint, internal rotation of the foot despite distal external tibial torsion, patella alta and shallow trochlear groove (Hulse, 1993; Towle et al., 2005; Kowaleski, 2006; Soparat et al., 2012).

Figure 3 Deformity of the distal femur and proximal tibia in severe MPL stifle. Based on Heuter-Volkmann principle, MPL causes increased pressure on medial side of active physis of femur (white arrows) which inhibit growth of femoral medial condyle, resulting in femoral varus. In contrast, the larger lateral femoral condyle leads to increased pressure on the lateral side of proximal tibia (black arrows), resulting in tibial valgus and external torsion. The yellow arrow heads demonstrate active physeal lines of the femur and tibia

3. Surgical correction of patellar luxation and pelvic limb deformities

There are many surgical techniques used for correcting PL, which are classified in to soft tissue and bone reconstructions (Piermattei et al., 2006; Witte and Scott, 2011). The aims of surgical correction are to realign quadriceps mechanism and to maintain patella in the normal position in the femoral sulcus. The result of the correction should provide a straight alignment with normal anatomy and function of the stifle joint and should improve limb use without lameness caused by MPL. In 1970, DeAngelis reported the 90.1% success rate of surgical procedures of tibial tuberosity transposition combined with trocheoplasty in cases of PL without other orthopedic problems of pelvic limbs, while the dogs with pathological conditions of the stifle joint co-existing with MPL, the success rate was 79% (DeAngelis and Hohn, 1970). Post-operative complications about 10-18% were reported in dogs and major complication was reluxation of approximately 6-9%. The higher grade of PL presents, the more complications occur (Arthurs and Langley-Hobbs, 2006; Gibbons et al., 2006; Alam et al., 2007). At present, the treatment option of recurrent medial patellar luxation associated with femoral varus and external femoral torsion is corrective osteotomy (Roch and Gemmill, 2008) (Figure 4). Moreover, in severe MPL with pelvic limb deformity, corrective osteotomy of femur and tibia was considered (Bruecker, 2006; Persuki et al., 2006; Roch and Gemmill, 2008). Therefore, an accurate evaluation of conformational deformity is necessary for the surgical planning. However, the criteria for the corrective osteotomy of femur and tibia in small-breed dogs have not been well described.

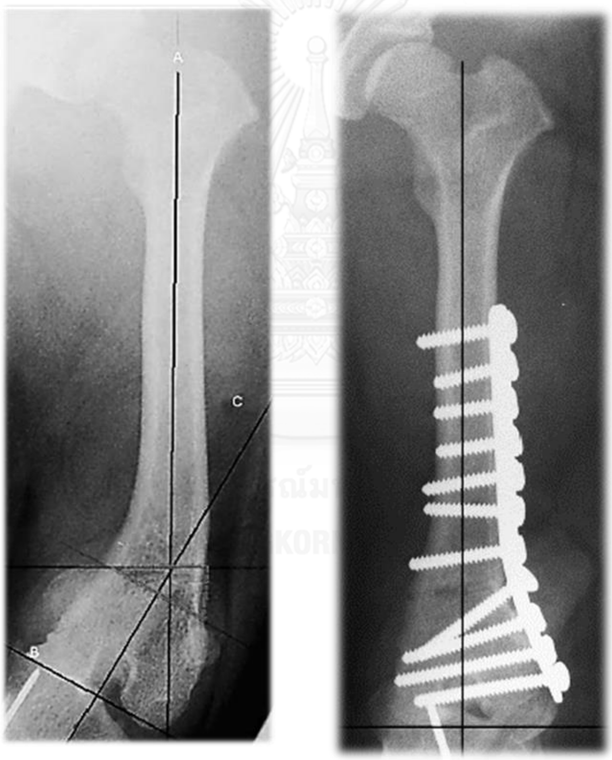
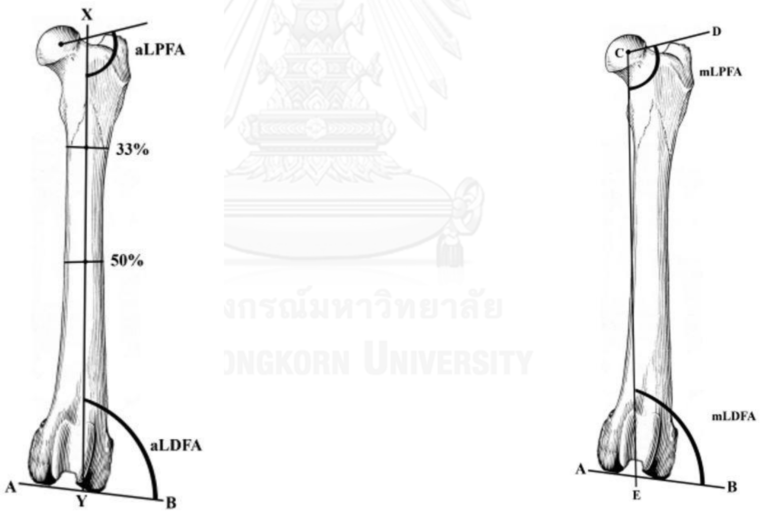


Figure 4 Corrective osteotomy of femoral varus. (A) Preoperative measurement of femoral varus. (B) Postoperative of corrective osteotomy of femoral varus. (Roch and Gemmill, 2008)

4. The measurement of hind limb deformities

4.1 Femur

The nomenclature and method for assessment of limb deformities in dogs were mostly adopted from human literatures (Paley, 2003). Every long bone has two longitudinal axes: anatomical and mechanical axes. The anatomical axis of a bone is a line passing through center of diaphysis and the mechanical axis is a line connecting between the center of proximal and distal joints. The joint reference lines are the horizontal lines which tangent to the marginal point of the proximal and distal joints of interest. The intersection between those longitudinal axes and joint reference lines create the specific angles of particular bone. In frontal plane, the pelvic limb angles indicate the degree of deformity called varus and valgus. The measurements of femoral angles in large-breed dogs have been described (Figure 5) and the reference values have been reported (Table 1) (Tomlinson et al., 2007).



(A) (B)

Figure 5 Drawing of femoral joint angles in frontal plane.

(A) Drawing of the anatomical lateral distal femoral joint angle (aLDFA) and the anatomical lateral proximal femoral joint angle (aLPFA). (B) Drawing of the mechanical lateral distal femoral joint angle (mLDFA) and the mechanical lateral proximal femoral joint angle (aLPFA). Line A-B is distal joint reference line; Line C-D is proximal joint reference line; Line C-E is the mechanical axis and line X-Y is the anatomic axis (Tomlinson et al., 2007).

In 2012, femoral angles in Pomeranians were first reported by Soparat et al. and the comparison of these angles between normal and medial patellar luxation stifles was made by using craniocaudal radiographs as shown in figure 6.

(A) (B)

Figure 6 Craniocaudal radiographs of stifles of Pomeranians.
(A) A craniocaudal radiograph of the stifles of a Pomeranian dog, showing the inclination angle (ICA), femoral varus angle (FVA), anatomical lateral distal femoral angle (aLDFA) and mechanical lateral distal femoral angle (mLDFA); (B) Craniocaudal radiographs of stifles of Pomeranian dogs in grades I-II MPL (left) and grade III MPL (right) (Soparat et al., 2012).

The measurements of femoral angles in three orthogonal planes in various breeds are shown in Table 1-2.

Table 1 Means ± SD of femoral angles in frontal plane reported in previous studies.

Breed category	Method	Status	aLDFA	mLDFA	aLPFA	mLPFA	ICA
Dudley et al., 2006							
Large breed	CrCd Radiograph	Normal	99.4±2.3	-	-	-	-
	CT		98.8±3.3	-	-	-	-
	Anatomic preparation		97.4±3.9	-	-	-	-
Tomlinson et al., 2007							
Labrador Retriever	CrCd radiograph	Normal	97±3.2	100±2.6	103±6.4	100±6.0	134±5.3
Golden Retriever			97±2.8	100±2.3	98±5.7	95±5.2	134±5.2
German Shepherd			94±3.3	97±3.1	101±5.0	97±4.5	132±5.9
Rottweiler			98±3.5	100±2.7	96±5.3	93±4.7	137±5.4
Swiderski et al., 2008							
Walker hound cadavers	CrCd Radiograph	Normal	95.8±1.0	-	-	-	-
	Anatomic preparation		95.2±2.1	-	-	-	-
Dismukes et al., 2008							
Medium-large breed cadavers	CrCd extended full limb radiographs	CrCLR	-	-	98.6±2.5	103.7±5.4	-
Mortari et al., 2009							
Small-medium breed	CrCd radiograph	MPL grade 1	103.0±7.8	-	-	-	131.2±5.3
		MPL grade 2	100.3±5.2	-	-	-	130.4±9.5
		MPL grade 3	107.8±6.9	-	-	-	133.8±12
		MPL grade 4	108.2±2.8	-	-	-	136.7±4.3

Table 1 (continue) Means ± SD of femoral angles in frontal plane reported in previous studies.

Breed category	Method	Status	aLDFA	mLDFA	aLPFA	mLPFA	ICA
Soparat et al., 2012							
Pomeranians	CrCd radiograph	Normal	95.2±3.5[a]	99.5±4.0[a]	-	-	136.5±7.1
		MPL grade 1-2	98.9±3.9[a]	101.7±3.1[a]	-	-	136.8±6.0
		MPL grade 3	103.2±5.9[b]	104.5±4.4[b]	-	-	139±9.0
Yasukawa et al., 2016							
Toy Poodles	CrCd radiograph	Normal	94.4±4[a]	99.1±3.1[a]	106.6±8.7[a]	102.1±8.8[a]	127.7±6.3
		MPL grade 2	94.3±4.8[a]	99.3±3.9[a]	107.6±6.3[a]	101.5±7.7	124.6±7.1
		MPL grade 4	110.5±8.5[b]	113.3±5.3[b]	96.5±8.4[b]	93.8±5.5[a]	125.0±6.1
	CT	Normal	90.3±2.8[a]	96.2±2.5[a]	119.5±5.7[a]	113.6±6.1	116.8±6.1
		MPL grade 2	89.5±3.8[a]	95.0±3.6[a]	118.7±4.4	113.1±3.9	118.0±6.8
		MPL grade 4	109.7±6.4[b]	111.1±6.9[b]	112.7±6.8[b]	109.7±6.4	118.3±9.3

[a,b] Mean values in the same study and the same column that have different superscript lower case letter are significntly different ($p<0.05$). aLDFA- anatomical lateral distal femoral angle; mLDFA- mechanical lateral distal femoral angle; aLPFA- anatomical lateral proximal femoral angle; mLPFA- mechanical lateral proximal femoral angle; ICA- inclination angle; CrCLR- cranial cruciate ligament rupture; MPL- medial patella luxation; CrCd- Craniocaudal; CT- computed tomography.

Table 2 Means ± SD of femoral angles in sagittal and axial plane reported in previous studies.

Breed category	Method	Status	aCdPFA	aCdDFA	PA	FTA
Dudley et al., 2006						
Large breed	Radiograph	Normal	-	-	-	16.0±6.4
	CT		-	-	-	19.6±7.9
	Anatomic preparation		-	-	-	18.9±5.4
Yasukawa et al., 2016						
Toy Poodles	CrCd radiograph	Normal	157.3 ± 7.7	104.3 ± 2.1	12.7 ± 4.1	-
		MPL grade 2	153.3 ± 8.0	104.5 ± 5.6	12.7 ± 7.1	-
		MPL grade 4	152.5 ± 11.3	105.6 ± 6.9	14.2 ± 7.3	-
	CT	Normal	153.3 ± 5.1	102.9 ± 3.2	11.2 ± 5.2	19.8 ± 4.6^{a}
		MPL grade 2	151.6 ± 6.0	102.6 ± 3.5	11.1 ± 5.4	16.6 ± 4.8^{a}
		MPL grade 4	151.7 ± 5.6	104.7 ± 5.7	15.8 ± 6.9	9.6 ± 5.2^{b}

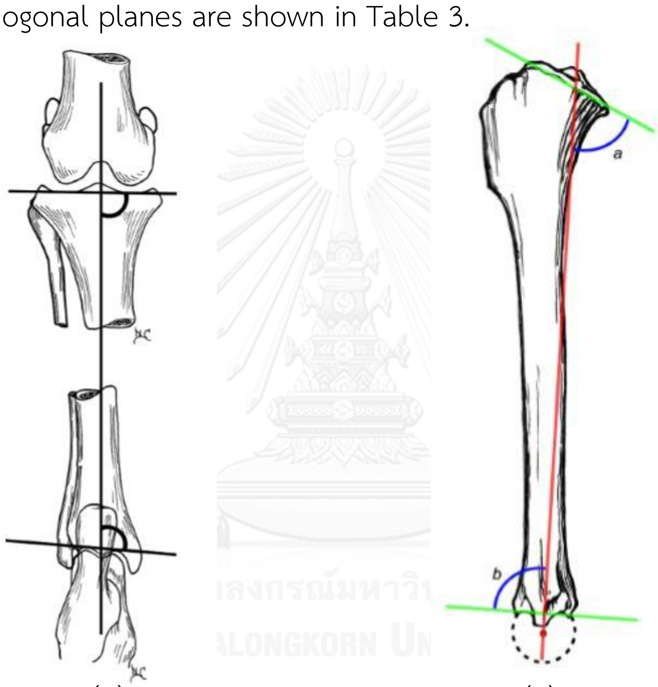
$^{a, b}$ Mean values in the same study and the same column that have different superscript lower case letter are significnty different (p<0.05).

aCdPFA- anatomical caudal proximal femoral angle; aCdDFA- anatomical caudal distal femoral angle; PA- precurvation angle; FTA- femoral torsion angle; CrCd- craniocaudal; MPL- medial patellar luxation; CT- computed tomography

4.2 Tibia

The principle of tibial angle assessment is similar to those in the femur. However, the conformation of the tibia is not straight so the anatomical axis is more difficult to identify than mechanical axis.

The evaluation of tibial radiographs in Labrador-retriever and large-breed dogs have been described in frontal and sagittal planes which are shown in Figure 7 (Dismukes et al., 2007; Dismukes et al., 2008). In small-breed dogs, only Toy poodle has been reported of tibial angles. The mean values of tibial angles in various breeds in three orthogonal planes are shown in Table 3.



(A) (B)

Figure 7 Mechanical axes and joint reference lines of the tibia in frontal and sagittal planes. (A) Frontal plane of the tibia: mechanical medial proximal tibial angle , mMPTA (top angle) and mechanical medial distal tibial angle, mMDTA (bottom angle) (Dismukes et al., 2007). (B) Medial aspect of tibia: mechanical caudal proximal tibial angle, mCdPTA (angle a) and mechanical cranial distal tibial angle, mCrDTA (angle b) (Dismukes et al., 2008).

Table 3 Means ± SD of tibial angles reported in previous studies.

Breed category	Method	Status	mMPTA	mMDTA	mCdPTA	mCrDTA	TTA
Dudley et al., 2006							
Large breed	Radiograph	Normal	-	-	-	-	16±6.4
	CT		-	-	-	-	19.6±7.9
	Anatomic preparation		-	-	-	-	18.9±5.4
Dismukes et al., 2007							
Labrador retrievers	Caudocranial radiograph	CrCLR	93.38±1.81	96.34±2.51	-	-	-
Medium-large breed			93.30±1.78	95.99±2.70	-	-	-
Dismukes et al., 2008							
Labrador retrievers	Mediolateral radiograph	CrCLR	-	-	63.8±3.7	81.7±4.2	-
Medium-large breed			-	-	63.6±3.7	81.6±4.2	-
Yasukawa et al., 2016							
Toy Poodles	Radiograph	Normal	94.4±3.8	96.5±2.3	62.5±4.7	91.0±4.6	-
		MPL grade 2	96.9±3.5	94.2±4.4	61.6±5.3	88.8±2.0	-
		MPL grade 4	-	-	-	-	-
	CT	Normal	94.8±2.1	96.5±4.1	68.7±3.3	98.5±3.8	$11.3±4.3^{a}$
		MPL grade 2	94.7±1.7	95.2±2.4	68.8±3.4	99.2±3.1	$13.0±7.9^{a}$
		MPL grade 4	94.5±4.4	98.5±4.1	67.3±4.2	98.6±6.4	$32.8±7.9^{b}$

Mean values in the same study and the same column that have different superscript lower case letter are significnt different (p<0.05). mMPTA-mechanical medial proximal tibial angle; mMDTA- mechanical medial distal tibial angle; mCdPTA- mechanical caudal proximal tibial angle; mCrDTA- mechanical cranial distal tibial angle; TTA- tibial torsion angle; CrCLR- cranial cruciate ligament rupture; MPL- medial patellar luxation; CT- computed tomography.

In veterinary medicine, the diagnosis of limb deformities is commonly based on two-dimensional radiography because of its widespread availability and inexpensiveness. An accurate radiographic positioning is very important during x-rays. Elevation of distal femur more than 5° could significantly increase the anatomical lateral distal femoral angle (aLDFA) in craniocaudal (CrCd) radiographs (Jackson and Wendelburg, 2012). The useful radiographic landmarks in a true CrCd radiographs are femoral trochear ridges and walls of intercondylar fossa. The less effective landmarks are lesser trochanter, nutrient foramen and fabellae (Jackson and Wendelburg, 2012; Aiken and Barnes, 2014). Nonetheless, if a proper position was made, the certain outcome could be expected. As described by Dudley et al. (2006), the accuracy of femoral varus and femoral torsion determined by radiographs did not differ from those by CT-scan and measurement in anatomic preparation.

Even though femoral varus measurement from radiographs is repeatable and reproducible, the over-estimation of true anatomic varus can be occurred. Therefore, if the radiographs indicate the excessive femoral varus, other imaging technique is required to confirm the finding (Swederski et al., 2008). Moreover, the angles in the axial plane, femoral torsion and tibial torsion angles, are difficult to measure on radiography. Tibial torsion could not be separated from tibial rotation in the radiograph with improper positioning (Apelt et al., 2005). Aper et al. (2005) developed a method to assess tibial torsion on CT-scan by calculating the torsional degree between proximal and distal axes of the tibia (Figure 8).

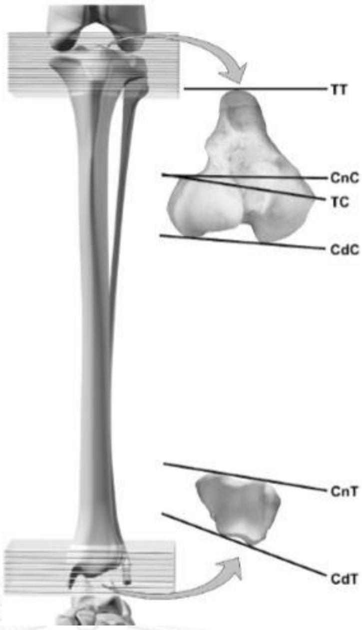


Figure 8 The illustrations of the femur, tibia, and tarsus in CT-scan. The transverse computed tomographic slices were obtained. The proximal and distal tibial axes include the transcondylar (TC) axis, the caudal condylar (CdC) axis, the distal cranial tibial (CnT) axis, and the distal caudal tibial (CdT) axis (Aper et al., 2005).

CT scan has been used since it provides three-dimensional images and less affected by positioning error. In 2016, Yasukawa et al. measured the pelvic limb deformities in Toy-Poodles with medial patellar luxation using CT-scan. They reported that many radiographic parameters were incomparable to those in CT-scan. Moreover, some angles were associated with MPL (Yasukawa et al., 2016) as shown in table 1-3 .

In small-breed dogs, study on the measurement of hind limb deformities is scarce (Soparat et al., 2012; Yasukawa et al., 2016). Therefore, the angular values of hindlimbs and the suitable method of limb deformities evaluation in Chihuahuas and Pomeranians are required.

CHAPTER III
MATERIALS AND METHODS

1. Animals

Chihuahua and Pomeranian dogs with normal and medial patellar luxation presented to surgical unit, small animal teaching hospital, Chulalongkorn University were included in this study. The owners signed the consent form to allow their dogs to involve in this study. Patients' age, sex, weight, and orthopedic conditions were recorded. Hind limbs of Chihuahuas and Pomeranians were examined and classified into 5 groups: normal stifle, grade 1, 2, 3 and 4 MPL stifles. The hind limbs of dogs without any orthopedic problem were classified as the normal group. Patients with history of previous surgery involving hip or stifle joints, or having other coexistent orthopedic diseases including cranial cruciate ligament rupture, coxofemoral joint luxation, and Legg-Calvé- Perthes were excluded. All stifles were assessed the grades of PL while dogs are conscious and under general anesthesia. Grading's of MPL were adopted from Singleton (1969) as shown in the table 4.

Table 4 The grade classification of medial patellar luxation (Singleton, 1969)

Grade	Clinical signs and physical examination
Grade 1	Patellar luxation occurs occasionally. Lameness is difficult to observe and may not be noticed. Patella can be manually luxated but returns to normal position when released. The stifle is in a straight line without hock abduction, when the stifle is flexed and extended.
Grade 2	Patellar luxation occurs frequently. Lameness is mild and intermittent. Patella luxateseasily with manual manipulation with foot rotated inward and stifle flexed. Patella remains luxates until stifle extension or manual replacement occurs. Crepitation may be apparent when patella luxates due to erosion of the articulating surface of the patella and femoral trochlear sulcus. The tibial tuberosity rotation may be

	found. The hock is abducted and the toes point inward when patella luxates medially.
Grade 3	Patella luxates permanently but can be manually replaced. Reluxation occurs spontaneously when manual pressure on the patella is removed. Lameness can be observed easily. Animal may still use the limb with the semi-flexed stifle position. Tibial rotation and torsion are always apparent. The hock is abducted when stifle is flexed, and adducted when stifle is extended.
Grade 4	Patella luxates continually and cannot be manually replaced. Severe lameness, the dogs may carry the limb or shift the weight to thoracic limbs. More severe tibial rotation and torsion may show.

2. Anesthesia

Radiography and CT scanning were performed during dogs under general anesthesia. Acepromazine 0.03-0.05 mg/kg and morphine 0.5 mg/kg were administered intramuscularly as premedication. Anesthesia was induced intravenously with propofol 4-6 mg/kg and maintained with isoflurane inhalation in 100% oxygen.

Table 5 The anesthetic protocol for dogs undergoing diagnostic imaging.

Procedure	Drug	Concentration	Dose	Route
Premedication	Acepromazine	1 mg/ml	0.03-0.05 mg/kg	intramuscular
	Morphine	10 mg/ml	0.5 mg/kg	intramuscular
Induction	Propofol	10 mg/ml	4-6 mg/kg	intravenous
Maintenance	Isoflurane in 100% oxygen		1-3 mg%	inhalation

3. Radiography

The radiography was taken using the computed digital radiographic system (FCR CAPSULA V VIEW workstation®).

3.1 Radiographic positioning

The radiographic positioning were two orthogonal planes: frontal and sagittal planes.

1) Frontal plane

Patients were positioned in dorsal and ventral recumbencies with hips and stifles extended and femur and tibia were parallel to the cassette and table in order to get craniocaudal (CrCd) and caudocranial (CdCr) radiographic views, respectively. The images had to include pelvic bone, coxofemoral joints, stifle joints, and tarsal joints. The criteria of the radiograph in frontal plane of the femur were the hip extended in neutral rotation, both femurs parallel to the pelvis and the cassette, 50% of the lesser trochanter seen at the medial aspect of the proximal femur, and the vertical walls of the intercondylar notch distinct parallel lines (Dudley et al., 2006; Soparat et al., 2012; Aiken and Barnes, 2014).

In craniocaudal and caudocranial radiographs of the tibia, medial aspect of tuber calcaneus had to align with the intermediate ridge of the tibia. The criterion to decide whether the positioning was corrected percent deviation (Figure 9A-B). Percent deviation was calculated by, first measuring the distance between medial aspects of tuber calcaneus to the intermediate ridge of tibia, then, dividing the distance by the distance between two arciform grooves of the cochlea tibiae at its most proximal point, and after that, multiplying by 100. If the percent deviation was more than 50%, the tibia would be excluded due to internal rotation or torsion (Dismukes et al., 2007).

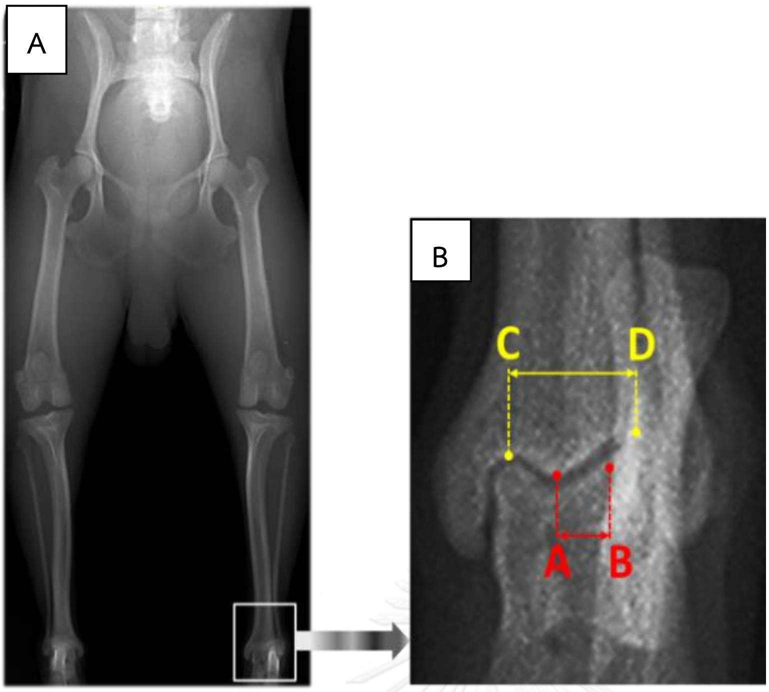


Figure 9 Caudocranial radiograph of the femur and tibia with percent deviation. (A) Caudocranial radiograph of the femur and tibia. (B) Percent deviation = (distance AB ÷ distance CD) x 100. A = intermediate ridge of tibia, B = medial aspect of tuber calcaneus, C = the most proximal point of the medial arciform groove of cochlea tibia, D = the most proximal point of the lateral arciform groove of cochlea tibia.

2) Sagittal plane

Mediolateral radiography was performed with the x-ray beam covering entire femur, tibia and tarsus. The beam was centered at the mid-tibial diaphysis with the normal flexion of the stifle and the tarsus. The mediolateral projection was acceptable when the femoral condyles were superimposed (Figure 10) (Dismukes et al., 2008).

Figure 10 Femoral condyles superimposed in mediolateral radiograph.

3.2 Radiographic measurement

3.2.1 Femur

1) Frontal plane

Joint reference lines were identified both proximally and distally. The proximal joint reference line is a line from the center of the femoral head to the most proximal point of the greater trochanter. The distal joint reference line is a line from the lateral to the medial condyles of the femur at their most distal aspects. The femoral anatomical axis was drawn by; first, measuring the length of the femur from the center of the intercondylar fossa to the most distal point of the dorsal aspect of the femoral neck. Second, two points were marked at the 1/3 and 1/2 of the femoral length at the center of the bone. Finally, an anatomical axis line was drawn through these two points and extended to the most proximal and distal aspect of the femur. The anatomical lateral proximal femoral angle (aLPFA) is the intersection of the femoral anatomical axis and the proximal joint reference line on the lateral side. The anatomical lateral distal femoral angle (aLDFA) is the intersection of the femoral anatomical axis and the distal joint reference line on the lateral side. Inclination angle (ICA) is the angle formed by the line drawn from the center of the femoral head to the femoral neck bisection point at its narrowest point and the anatomical axis (Figure 11A). The mechanical axis is the line drawn from the center of the femoral head to the center of the intercondylar fossa at its most proximal aspect. The mechanical lateral proximal femoral angle (mLPFA) is the intersection of the mechanical axis and the proximal joint reference line. The mechanical lateral distal femoral angle (mLDFA) is the intersection of the mechanical axis and the distal joint reference line (Figure 11B) (Dudley et al., 2006; Tomlinson et al., 2007; Soparat et al., 2012).

2) Sagittal plane

The measurement was performed in the mediolateral view of the femur. The proximal anatomical axis (PAA) of the femur is the line which bisects the proximal femur. The distal anatomical axis (DAA) of the femur is the line which bisects the distal femur. The distal reference line of the femur is drawn perpendicular to the line between the lesser trochanter and the proximal limit of the trochlear groove. The femoral neck axis (FNA) is the line bisects the femoral neck. The anatomical caudal proximal femoral angle (aCdPFA) is the angle between the PAA and FNA on the caudoproximal side. The anatomical caudal distal femoral angle (aCdDFA) is angle between the DAA and the distal reference line of the femur on the caudodistal side. The procurvation angle (PA) is the intersection of the proximal and distal anatomical axis of the femur (Figure 11C) (Paley, 2003; Petazzoni and Jaeger, 2008).

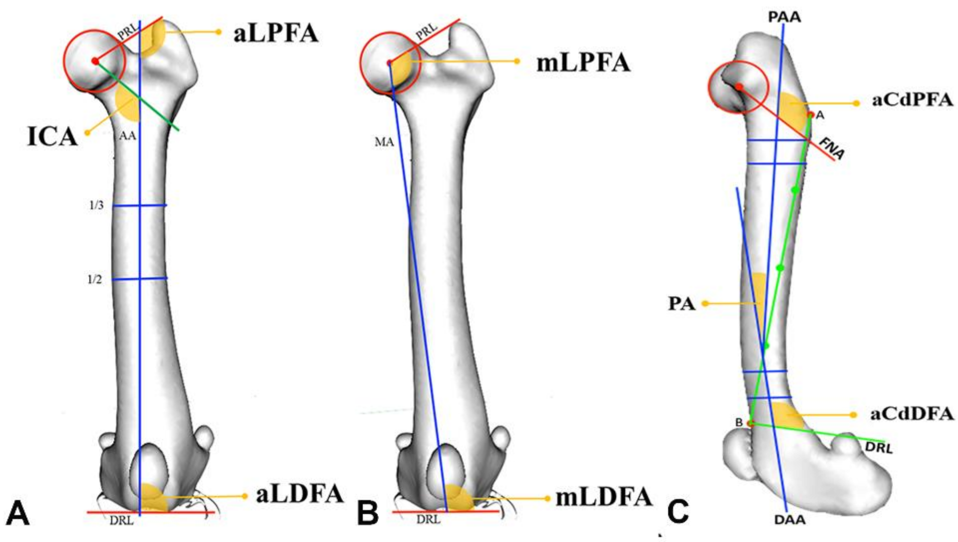


Figure 11 The angle measurement of the femur in frontal and sagittal planes. (A) Anatomical axis and angles of the femur in frontal plane: AA = anatomical axis, aLPFA = anatomical lateral proximal femoral angle, aLDFA = anatomical lateral distal femoral angle. ICA = Inclination angle. (B) Mechanical axis and angles of the femur in frontal plane: MA = mechanical axis, mLPFA = mechanical lateral proximal femoral angle, mLDFA= mechanical lateral distal femoral angle, (C) Sagittal plane of the femur: PAA = proximal anatomical axis, DAA = distal anatomical axis, FNA = femoral neck axis, DRL = distal reference line, A = lesser trochanter, B= proximal limit of trochlear groove, PA = procurvation angle, aCdPFA = anatomical caudal proximal femoral axis, aCdDFA = anatomical caudal distal femoral axis.

3.2.2 Tibia

1) Frontal plane

The proximal joint reference line is the line connecting the most distal points of the subchondral bone concavities of the medial and lateral tibial condyles. The distal joint reference line is the line connecting the most proximal points of the two arciform grooves of the cochlea tibiae (Dismukes et al., 2007). The mechanical axis is the line drawn from the center of the intercondylar fossa of the tibia at its most proximal aspect to the distal intermediate ridge of the tibia at its most distal aspect. The mechanical medial proximal tibial angle (mMPTA) is formed by the mechanical axis and the proximal joint reference line on the medial side. The mechanical medial distal tibial angle (mMDTA) is formed by the mechanical axis and the distal joint reference line on the medial side (Figure 12A).

2) Sagittal plane

The proximal joint reference line is the line drawn from the cranial aspect point to the caudal aspect point of the medial tibial condyle. The distal joint reference line is drawn from the distal aspect of the distal intermediate ridge of the tibia to the caudodistal aspect of the cochlea tibia. The mechanical axis is the line drawn from the midpoint between the tibial intercondylar eminences to the center of the talus (Dismukes et al., 2008). The mechanical caudoproximal tibial angle (mCdPTA) is the angle formed by the mechanical axis and the proximal joint reference line on the caudoproximal side. The mechanical craniodistal tibial angle (mCrDTA) is the angle formed by the mechanical axis and the distal joint reference line on the craniodistal side (Figure 12B).

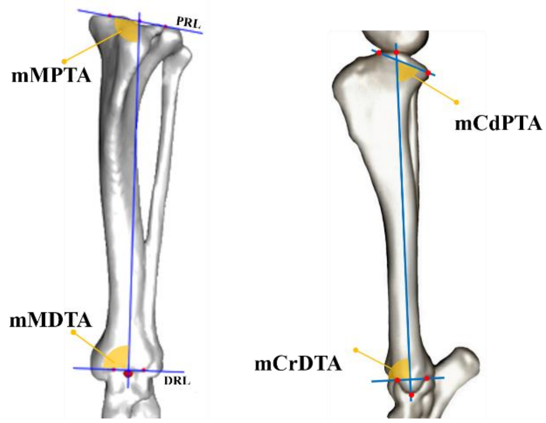


Figure 12 The angle measurement of the tibia in frontal and sagittal planes. (A) Frontal plane of the tibia: mMPTA = mechanical medial proximal tibial angle, mMDTA = mechanical medial distal tibial angle. (B) Sagittal plane of the tibia: mCdPTA = mechanical caudal proximal tibial angle, mCrDTA = mechanical cranial distal tibial angle.

4. Computed tomography

Computed tomography (CT) images were acquired in a 64-slice helical CT scanner (OPTIMA 660, GE healthcare) and were processed using Multiplanar Reconstruction software (AW volumeshare 5 workstation,GE). Dogs were positioned in dorsal recumbency with both hip and stifle extension.

4.1 Frontal plane

The aLPFA, aLDFA, mLPFA, mLDFA, FVA, and ICA were measured in the frontal view of the femur. These angles were evaluated by the same method as that used in the radiographic images. The mMPTA and mMDTA were measured in the frontal view of the tibia. These angles were evaluated by the same method as for the radiographic images.

4.2 Sagittal plane

In CT scan, the measurements were performed in MPR images at lateral view of the femur. The procurvation angle (PA), the anatomical caudal proximal and distal femoral angle (aCdPFA and aCdDFA), the mCdPTA, and mCrDTA were measured by the same method as described for the radiographic images.

4.3 Axial plane

The femoral head and neck axis (FHNA) is the line drawn from the femoral head center to the line bisecting the femoral neck. The femoral transcondylar axis (FTCA) is the line tangential to the caudal surface of the femoral condyles. The femoral torsion angle (FTA) or femoral anteversion angle is formed by an intersection between the FHNA and FTCA (Figure 13) (Dudley et al., 2006; Yasukawa et al., 2016).

For the tibial torsion angle (TTA), the CT slices were chosen at the specific anatomic landmarks that can be most clearly observed. The proximal transcondylar (TC) axis is the line connecting the caudolateral extent of the extensor sulcus to the prominence at the medial collateral ligament insertion. The distal cranial tibial (CnT) axis is defined as the line parallel to the cranial tibial cortex immediately proximal to the talocrural joint. The angle formed by the TC and CnT axis is TTA. Clockwise deviation from the parallel line of the cranial tibial cortex as described as a negative value which indicate the internal torsion of tibia. (Figure 14) (Apelt et al., 2005; Aper et al., 2005).

Using Multiplanar Reconstruction (MPR), the CT image of each bone was processed and adjusted specifically in three orthogonal planes to establish the corrected position and landmarks before measurement (Figure 15).

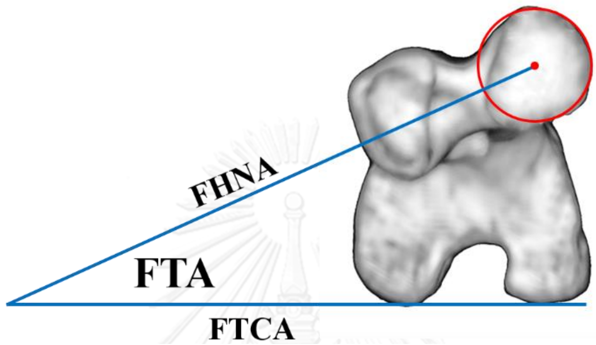


Figure 13 The measurement of femoral torsion in axial plane.

FHNA = femoral head and neck axis (proximal axis), FTCA = femoral transcondylar axis (distal axis), FTA = femoral torsion angle (angle between FHNA and FTCA).

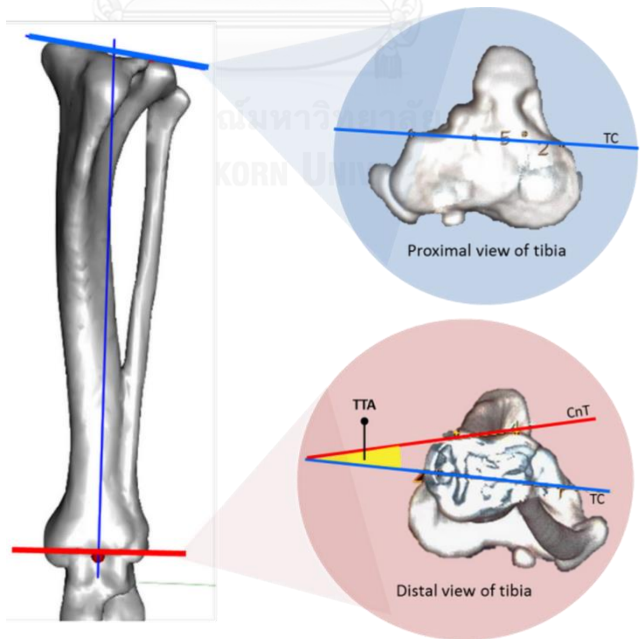


Figure 14 The measurement of tibial torsion in axial plane.

TC = transcondylar axis (proximal axis), CnT = cranial tibial axis (distal axis), TTA = tibial torsion angle (angle between TC and CnT).

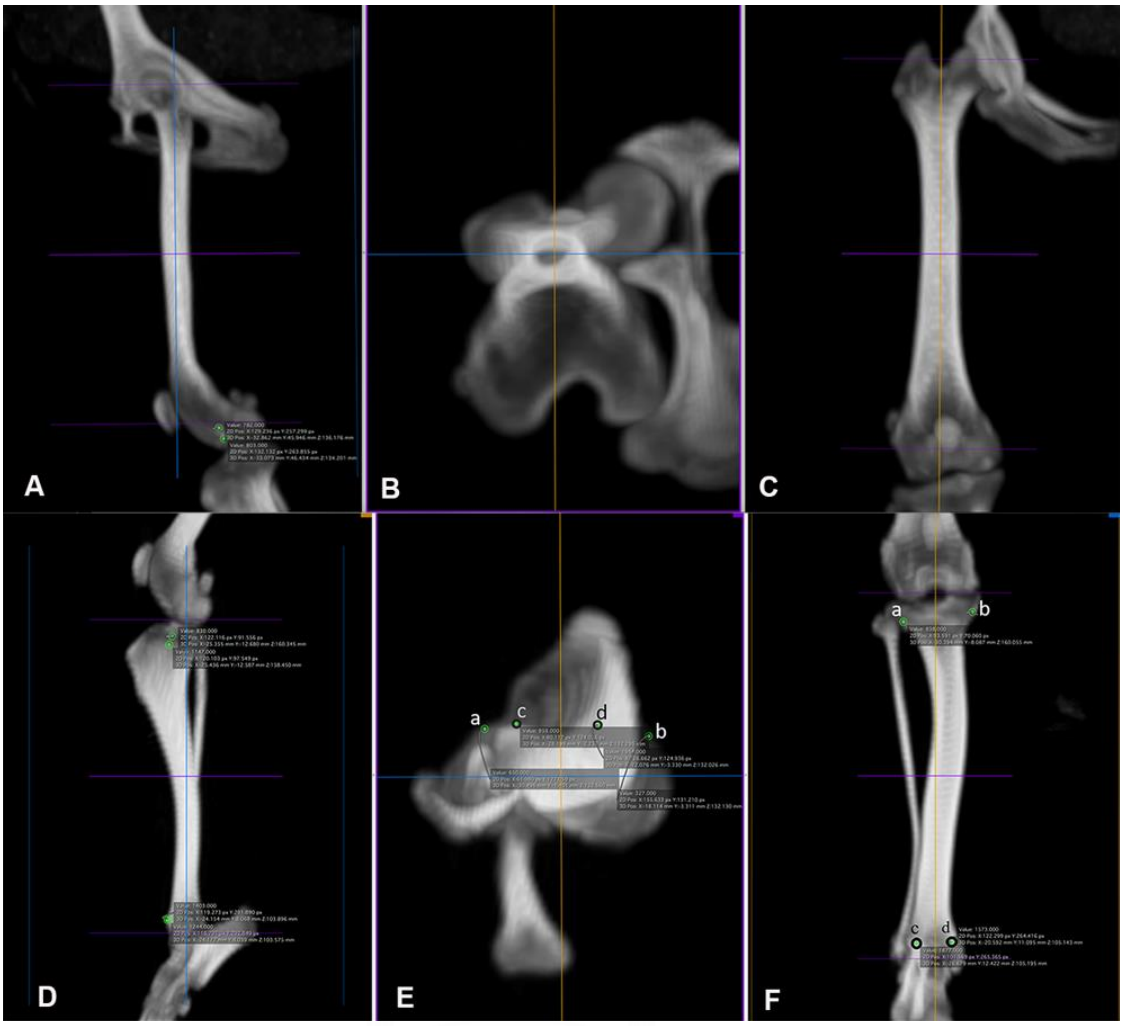


Figure 15 The processed images in Multiplanar Reconstruction Computed Tomography (MPR CT). The three orthogonal planes were adjusted to correct axes before measurement. The important anatomical landmarks were identified through slice thickness modification. (A) = sagittal plane of the femur, (B) = axial plane of the femur, (C) = frontal plane of the femur, (D) = sagittal plane of the tibia, (E) = axial plane of the tibia, and (F) = frontal plane of the tibia. The small dots (a-d) are the examples of landmark identification for tibial torsion angle. The small dots marks in an axis also appear in other orthogonal planes at the same time. a = caudolateral extent of the extensor sulcus, b = prominence at the medial collateral ligament insertion, c and d = the marginal points at cranial tibial cortex immediately proximal to the talocrural joint.

5. Statistical analysis

Age, weights and pelvic limb angular values were reported as mean ± SD. Genders was reported as female: male ratio. The data retrieved by the radiographic and CT-scan methods in each subject were compared using general linear model (repeated measurement). Mauchly’s test of sphericity was used to test the assumption of equal variances. The angles of dogs with different grades of MPL were tested for normality of data and analyzed by one-way ANOVA. Statistical analysis was implemented by using the statistic package SPSS program (version 22.0.0, IBM corp.). The results were statistically significant if p-value is less than 0.05.

CHAPTER IV
RESULTS

1. Chihuahuas

Sixty hindlimbs from 30 Chihuahuas were examined and graded for patellar status including 12 limbs with normal stifles and 13, 13, 14, and 8 limbs with grade 1, 2, 3, 4 MPL, respectively. The mean age of the Chihuahuas was 3.07 ± 2.52 years (range 6 – 96 months). The mean of body weights was 2.76 ± 0.97 kg (range 1 - 5 kg). The female: male ratio was 1.73 (table 6). One hind limb in grade 4 MPL was excluded due to abnormal conformation of the proximal femur. The data of the 30 Chihuahuas are shown in Appendix A.

Table 6 Sex, age and weight of 30 Chihuahuas with normal and MPL stifles.

Groups	Amount of hindlimbs	Age (years)	Weight (kg)
Normal	12	3.78±2.85	2.81±0.65
MPL 1	13	2.54±2.13	2.41±0.94
MPL 2	13	3.71±2.86	3.05±0.87
MPL 3	14	2.67±1.99	2.72±0.94
MPL 4	8	2.96±2.88	2.83±1.21
Total	60	3.07 ± 2.52 (range 0.5 –8)	2.76 ± 0.97 (range 1 - 5)

Means ± SD of the pelvic limbs obtained from radiography and CT scan of the 30 Chihuahuas in frontal plane (aLPFA, mLPFA, aLDFA, mLDFA, ICA, mMPTA and mMDTA) are shown in table 7. Means ± SD of the pelvic limbs in sagittal plane (PA, aCdPFA, aCdDFA, mCdPTA and mCrDTA) and transverse plane (FTA and TTA) are shown in table 8. The processed images with unclear landmarks were excluded from analysis.

The radiographic angles with significant differ from those in CT-scan measurements were: aLPFA and mLPFA in both CrCd and CdCr radiographs, mMPTA in CdCr radiograph, PA, aCdPFA, and aCdDFA in normal stifles. Besides the disparities in the normal stifles, the angles in the MPL stifles were fluctuated. However, the values of mMPTA in the CrCd radiographs was not significantly different from those in the CT-scan in the normal and all grade of MPL stifles.

There were no statistical differences of aLDFA, mLDFA, ICA, mMDTA, mCdPTA and mCrDTA from radiography and CT-scan in the normal stifles. aLDFA from both CrCd and CdCr radiographs were not significantly different from CT-scan in normal and grade 1 MPL stifles, while only the CrCd radiographs of mLDFA was not significantly different to those from the CT-scan in the normal and the grade 1 MPL stifles. mMDTA in CrCd radiographs was not significantly different from CT-scan in all grades of MPL. mCdPTA of all grades MPL in the radiographs was not significantly different to that in the CT-scan. mCrDTA of all grade MPL except grade 2 in the radiographs was not significant different from that in the CT-scan. Based on the CT-scan, the angles related to severity of MPL were aLDFA, mLDFA, mMPTA, FTA and TTA.

Table 7 The frontal and tibial angles (Mean ± SD) evaluated from radiographic and computed tomographic (CT) measurements in frontal planes in the normal and the MPL stifles of Chihuahuas.

Angles	Normal			MPL 1			MPL 2			MPL 3			MPL 4		
	Radiography		CT	Radiography		CT	Radiography		CT	Radiography		CT	Radiography		CT
	CrCd	CdCr		CrCd	CdCr		CrCd	CdCr		CrCd	CdCr		CrCd	CdCr	
Femur															
ICA	133.6±6.6^{a}	132.3±3.2	133.3±5.7	133.9±3.5^{a}	134.2±6.0	134.3±7.2	132.5±4.4^{a}	134.7±6.4	133.4±5.2	135.2±8.4^{a}	132.8±7.9	133.7±4.9	141.8±7.6^{b†}	137.5±8.6	129.5±7.0‡
aLPFA	112.4±5.0†	110.7±6.3†	123.5±7.4‡	111.4±6.4†	108.8±5.6†	121.1±4.2‡	115.9±7.7†	110.3±8.6†	122.4±7.3‡	113.8±8.3†	110.5±9.7†	122.5±7.1‡	108.6±11.7†	103.8±16.4†	124.0±7.4‡
mLPFA	108.8±7.9†	106.3±6.8†	119.6±7.5‡	109.3±7.5†	105.3±6.0‡	117.8±5.2§	112.6±8.3†	107.3±8.6‡	120.5±8.6§	113.4±8.1†	107.8±9.4‡	118.9±8.4§	109.6±9.1†	104.2±11.4†	120.9±6.1‡
aLDFA	99.4±4.5^{a}	96.2±3.6^{a}	96.6±3.7^{a}	100.8±3.1^{a}	99.8±5.1^{ab}	97.6±3.9^{a}	100.7±3.0^{a†}	100.8±3.5^{ab†‡}	97.6±3.6^{a‡}	102.7±3.1^{a†}	102.1±5.1^{b†‡}	98.7±4.2^{a‡}	114.6±11.5^{b†}	112.1±13.3^{c†‡}	105.5±5.7^{b‡}
mLDFA	102.0±3.2^{a}	100.2±3.8^{a}	100.4±3.2^{a}	102.5±3.5^{a†‡}	103.0±3.4^{a†}	100.3±2.0^{a‡}	103.2±2.0^{a†}	103.4±2.5^{ab†‡}	101.3±2.6^{a‡}	104.6±2.2^{a†‡}	104.6±3.0^{b†}	102.7±3.3^{a‡}	113.5±8.0^{b}	112.1±8.9^{c}	108.0±4.7^{b}
Tibia															
mMPTA	94.4±0.9^{a†}	98.2±2.5^{a‡}	95.6±3.4^{a†}	96.9±3.1^{b†‡}	97.3±2.9^{a†}	96.0±3.0^{a‡}	94.7±3.3^{a}	97.1±3.3^{a}	96.7±3.3^{a}	96.2±2.3^{a}	98.4±2.7^{a}	96.7±3.3^{a}	99.6±7.0^{b}	103.1±7.2^{b}	103.5±9.3^{b}
mMDTA	95.3±3.3^{a}	93.2±1.1^{a}	92.3±6.4	92.3±4.6^{a†‡}	94.9±3.6†	91.8±4.9‡	93.6±3.9^{a}	93.3±2.4^{a}	92.6±4.4	92.1±2.7^{a†}	95.0±2.4‡	91.9±2.6†	100.3±6.2^{b}	97.3±4.2^{b}	95.7±2.9

†, ‡, §: In each grade, the different superscript symbols in the same row indicate a significant difference of the angular values ($p<0.05$) between the imaging techniques. $^{a, b, c}$: In each row, mean values obtained from the same imaging techniques that have different superscript letters are significantly different between the MPL grades ($p<0.05$). aLPFA = anatomical lateral proximal femoral angle; mLPFA mechanical lateral proximal femoral angle, aLDFA = anatomical lateral distal femoral angle, mLDFA = mechanical lateral distal femoral angle; ICA = inclination angle; mMPTA = mechanical medial proximal tibial angle; mMDTA = mechanical medial distal tibial angle; CrCd = Craniocaudal radiographs; CdCr = Caudocranial radiographs

Table 8 The femoral and tibial limb angles (Mean ± SD) evaluated from radiographic and computed tomographic (CT) measurements in sagittal and axial planes in the normal and the MPL stifles of Chihuahuas.

Grade	Normal		MPL 1		MPL 2		MPL 3		MPL 4	
Sagittal plane	Mediolateral	CT	Mediolateral	CT	Mediolateral	CT	Mediolateral	CT	Mediolateral	CT
PA	8.1±3.9†	12.0±3.3‡	7.3±2.7†	10.1±3.4‡	7.0±3.4	7.5±2.9	7.2±5.2	8.4±6.2	6.9±5.0	10.3±6.3
aCdPFA	148.8±7.2†	159.9±5.8‡	152.9±8.4^{a}	155.1±7.9	148.0±7.0	149.7±4.6	152.7±7.0	148.6±6.8	141.4±8.1^{c}	147.3±6.5
aCdDFA	102.6±2.8†	106.3±2.8‡	101.4±1.9†	103.6±2.9‡	100.0±4.5	101.8±4.0	100.8±3.3†	102.7±4.5‡	102.3±5.5	102.6±6.4
mCdPTA	64.0±1.7	64.6±2.6	63.3±4.3	64.3 ±7.5	64.1±2.3	6.3 ±3.5	64.1±4.1	62.1±5.2	65.1±3.3	58.3±4.9
mCrDTA	90.8±2.5	94.0±3.5	92.4±4.1^{a}	91.3±5.1	88.0±2.3^{b†}	91.9±4.3‡	92.0±4.0	91.4±5.4	88.3±4.4	96.3±4.1
Transverse plane										
FTA	NE	29.8± 5.6^{a}	NE	27.7±4.5	NE	27.6±6.5	NE	25.8±6.0	NE	23.7±5.1^{b}
TTA	NE	7.1±3.7^{a}	NE	11.0±6.0^{a}	NE	8.5±5.7^{a}	NE	9.8±5.0^{a}	NE	19.7±13.0^{b}

†, ‡, §: In each grade, the different superscript symbols in the same row indicate a significant difference of the angular values ($p<0.05$) between the imaging techniques. $^{a, b, c}$: In each row, mean values obtained from the same imaging techniques that have different superscript letters are significantly different between the MPL grades ($p<0.05$). PA = precurvation angle; aCdPFA = anatomical caudal proximal femoral angle; aCdDFA = anatomical caudal distal femoral angles; mCdPTA mechanical caudal proximal tibial angle; mCrDTA = mechanical cranial distal tibial angle; FTA = femoral torsion angle; TTA = tibial torsion angle; NE = not evaluated.

2. Pomeranians

Sixty hindlimbs from 36 Pomeranians were examined and graded for patellar status including 22 limbs with normal stifles and 8, 10, 10, and 10 limbs with grade 1, 2, 3, 4 MPL, respectively. The mean of age of the 36 Pomeranians was 2.49 ± 2.43 years (range 5 – 120 months). The mean body weight was 3.15 ± 1.29 kg (range 1.2 – 8.1 kg). The female: male ratio was 1.72 (Table 9). In the normal group, 12 out of 22 limbs were evaluated only by radiography due to inconvenience of the owners. Three radiographic images of hind limbs with grade 4 MPL were excluded due to severe deformities making proper positioning and landmark identification impossible. The raw data of the 36 Pomeranians are shown in Appendix B.

Table 9 Sex, age and weight of 36 Pomeranians with normal and MPL stifles.

Groups	Amount of hindlimbs	Age (years)	Weight (kg)
Normal	22	2.69 ± 2.39	3.16±1.46
MPL 1	8	2.03 ± 1.56	2.38 ± 0.80
MPL 2	10	2.3 ± 3.41	3.09 ± 0.52
MPL 3	10	2.59 ± 2.32	3.57 ± 1.48
MPL 4	10	1.50 ± 1.17	2.97 ± 1.08
Total	60	2.49 ± 2.43 (range 0.42–10)	3.15 ± 1.29 (range 1.2-8.1)

Means of the pelvic limb angles in frontal plane (LPFA, mLPFA, aLDFA, mLDFA, ICA, mMPTA and mMDTA) evaluated from radiography and CT scan of the 36 Pomeranians are shown in table 10. Means of pelvic limb angles in sagittal planes (PA, aCdPFA, aCdDFA, mCdPTA and mCrDTA) and axial plane (FTA and TTA) are shown in tables 10-11. The processed images with unclear landmarks were excluded from analysis.

The angles with significant differences found between those from the radiographic and CT-scan measurements in normal stifles were aLPFA and mLPFA (both CrCd and CdCr), PA, and aCdPFA.

There were no significant differences of aLDFA, mLDFA, ICA, mMPTA, mMDTA, from CrCd and CdCr radiography and CT-scan in the normal stifles. The difference between radiography and CT-scan of aCdDFA, mCdPTA and mCrDTA were not found in normal stifles.

The CrCd and CdCr radiographs of aLDFA, mLDFA and mMPTA were not significantly different from those in CT-scan up to MPL grade 3. The radiographs of ICA, mMDTA, aCdDFA, mCdPTA and mCrDTA were not significantly different from those in CT -scan in all groups.

aLDFA, mLDFA and FTA of MPL grade 4 were significantly different from other groups from CT-scan.

Table 10 The femoral and tibial angles (Mean ± SD) evaluated from radiographic and computed tomographic (CT) measurements in frontal planes in the normal and the MPL stifles of Pomeranians.

Grade	Normal			MPL1			MPL2			MPL3			MPL4		
	Radiography		CT	Radiography		CT	Radiography		CT	Radiography		CT	Radiography		CT
	CrCd	CdCr		CrCd	CdCr		CrCd	CdCr		CrCd	CdCr		CrCd	CdCr	
Femur															
aLPFA	109.0±7.1†	108.2±3.9†	121.1±4.0‡	113.0±5.8†	109.2±10.4†	120.9±4.7‡	108.8±5.5†	103.2±3.8†	116.8±6.8‡	107.9±4.0†	108.2±5.2†	118.9±4.6‡	106.25±7.3†	101.4±11.3†	118.0±8.0‡
mLPFA	106.3±6.7†	104.5±8.0†	118.2±3.9‡	111.2±6.7†	106.4±10.0†	119.5±5.5‡	106.0±5.7†	101.6±5.7†	115.3±7.4‡	106.0±3.6†	103.9±5.1†	116.7±4.2‡	105.8±8.1†	101.1±12.0†	115.2±9.4‡
aLDFA	98.5±3.2^{a}	97.5±3.1^{a}	97.4±3.3^{a}	99.2±1.7^{a}	97.6±4.4^{a}	99.3±2.5^{ab}	100.1±4.4^{a}	99.8±3.8^{a}	98.7±3.0^{ab}	101.4±4.4^{ab}	99.2±2.7^{a}	99.9±4.8^{ab}	107.0±7.2^{b†‡}	111.8±11.9^{b†}	101.8±6.2^{b‡}
mLDFA	100.9±2.8^{a}	101.5±4.2^{a}	100.6±3.4^{a}	102.3±2.0^{a}	101.8±3.0^{a}	101.1±2.0^{ab}	103.4±2.0^{ab}	102.8±3.9^{a}	102.4±2.7^{ab}	103.4±4.2^{ab}	103.2±2.3^{a}	101.7±3.8^{ab}	108.2±6.9^{b}	112.5±10.6^{b†}	104.6±5.8^{b‡}
ICA	135.2±5.1	135.1±6.7	133.6±5.5	135.6±7.5	136.6±5.4	135.3±3.7	135.3±6.9	136.8±3.5	134.7±7.4	138.1±4.5	133.0±6.0	135.0±4.2	139.4±6.9	141.8±9.7	137.8±5.6
Tibia															
mMPTA	93.5±2.7^{a}	94.3±2.6^{a}	93.3±2.3	94.5±1.3^{ab}	94.3±1.2^{ab}	93.5±1.2	96.7±4.3^{abc}	96.3±2.2^{ab}	94.0±4.6	98.1±3.2^{bc}	95.1±2.3^{ab}	94.3±3.3	100.4±5.0^{c†}	97.4±2.4^{b}	96.4±3.7‡
mMDTA	93.1±4.1	93.1±2.2^{a}	91.3±2.2	95.1±3.0	96.6±3.6^{ab}	92.4±2.9	96.8±3.3†	95.6±1.9^{ab†}	92.0±1.9‡	94.4±3.7	97.2±4.0^{b†}	92.1±3.8‡	95.7±4.1	97.8±3.6^{b}	95.5±5.3

$^{\dagger, \ddagger, \S}$: In each grade, the different superscript symbols in the same row indicate a significant difference of the angular values ($p<0.05$) between the imaging techniques. $^{a, b, c}$: In each row, mean values obtained from the same imaging techniques that have different superscript letters are significantly different between the MPL grades ($p<0.05$). aLPFA = anatomical lateral proximal femoral angle; mLPFA mechanical lateral proximal femoral angle, aLDFA = anatomical lateral distal femoral angle, mLDFA = mechanical lateral distal femoral angle; ICA = inclination angle; mMPTA = mechanical medial proximal tibial angle; mMDTA = mechanical medial distal tibial angle; CrCd = Craniocaudal radiographs; CdCr = Caudocranial radiographs.

Table 11The femoral and tibial angles (Mean ± SD) evaluated from radiographic and computed tomographic (CT) measurements in sagittal and axial planes in the normal and the MPL stifles of Pomeranians.

	Normal		MPL 1		MPL 2		MPL 3		MPL 4	
Sagittal plane	Radiography	CT	Radiography	CT	Radiography	CT	Radiography	CT	Radiography	CT
PA	11.5±4.2[†]	11.3±4.2[‡]	12.8±2.6[†]	14.1±2.1[‡]	12.8±13.2	13.2±3.0	11.9±2.4	12.3±3.0	12.4±4.4[†]	11.9±4.1[‡]
aCdPFA	149.6±7.5[†]	143.3±5.1[‡]	149.5±8.3	146.3±4.9	151.6±6.2	148.9±8.3	144.2±6.1	148.1±7.0	142.4±10.0[†]	151.5±9.9[‡]
aCdDFA	103.2±2.2	102.9±2.3	104.6±2.0	105.5±2.0	104.7±2.0	104.3±2.4	101.4±5.5	103.2±2.7	102.7±5.6	103.4±3.3
mCdPTA	67.9±2.7	66.0±3.1	73.0±10.6	67.9±4.2	67.7±3.4	69.1±4.1	64.7±7.3	70.0±3.5	68.4±6.7	67.1±3.3
mCrDTA	90.8±2.3	89.9±1.8	93.5±2.9	91.0±4.6	92.1±2.3	93.9±4.1	93.6±3.9	90.9±2.6	91.0±5.26	93.0±4.4
Transverse plane	Radiography	CT	Radiography	CT	Radiography	CT	Radiography	CT	Radiography	CT
FTA	NE	33.2±6.8[a]	NE	29.1±6.0[a]	NE	26.8±5.4[a]	NE	29.6±8.3[a]	NE	21.3±7.6[b]
TTA	NE	17.64.7	NE	15.5±9.6	NE	19.3±5.0	NE	19.3±5.0	NE	19.6±11.3

[†], [‡], [§]: In each grade, the different superscript symbols in the same row indicate a significant difference of the angular values ($p<0.05$) between the imaging techniques. [a, b, c]: In each row, mean values obtained from the same imaging techniques that have different superscript letters are significantly different between the MPL grades ($p<0.05$). PA = procurvation angle; aCdPFA = anatomical caudal proximal femoral angle; aCdDFA = anatomical caudal distal femoral angles; mCdPTA mechanical caudal proximal tibial angle; mCrDTA = mechanical cranial distal tibial angle; FTA = femoral torsion angle; TTA = tibial torsion angle; NE = not evaluated.

CHAPTER V
DISCUSSION

1. The comparison of angular values between radiography and CT-scan

In veterinary practice, radiography is widely used to assess the pelvic limb alignment although positioning error is likely to occur in case of pelvic limb deformities. CT-scan seems to be superior to radiography for determining the magnitude of pelvic limb conformation and abnormalities. This technique is suggested in dogs with severe limb deformity and is reported to be more accurate than radiography (Kowaleski, 2006; Palmer, 2008). Nonetheless, another study implied that there was no difference between radiography, CT-scan and anatomic preparation (Dudley et al., 2006).

This study, found that distal femoral angles measured from radiographs were comparable to those from CT-scan. The aLDFA and mLDFA evaluated from both CrCd and CdCr radiographs were comparable to those from the CT-scan in normal and low grade MPL stifles (≤ 1 MPL for aLDFA and grade 2 MPL for mLDFA) of Chihuahuas and up to grade 3 MPL in Pomeranians. However, CT-scan rather than radiographs should be performed to assess the aLDFA if the MPL is higher than grade 2 in Chihuahuas and higher than grade 3 in Pomeranians when deformity is suspected. According to the previous study, the well positioned radiographs and the CT-scan were reported to be accurate for the measurement of distal femoral angles in normal limbs of medium-to-large breed dogs (Dudley et al., 2006). Based on our results, the radiographic measurement of mLDFA was less accurate than aLDFA especially in Chihuahuas. This angle is formed by the mechanical axis which is drawn from the proximal femur. As stated in the result, the proximal femoral angles (aLPFA and mLPFA) from radiographs were uncertain and might cause the radiographic measurement of mLDFA unreliable. Previous studies reported that the femoral varus was difficult to assess from the radiography (Swederski et al., 2008; Jackson and Wendelburg, 2012). The mean values of the ICA from the CrCd and CdCr radiographs did not differ from the CT in the normal stifles and grade 1-3 MPL stifles in Chihuahuas, as well as in the normal stifles and all grade of MPL in Pomeranians.

The proximal femoral angles (aLPFA and mLPFA) from the radiographs were incomparable to those from the CT-scan. Unlike the distal part of femur, the proximal femur was more difficult to manipulated during radiography. A slight positioning error was likely to cause the inclination of the greater trochanter. This might directly affect the proximal joint reference line which forms the proximal femoral angles.

In the sagittal view of the femur, the radiographs were not commensurate with the CT-scan except aCdDFA in Pomeranians. Chihuahuas and Pomeranians have a small lesser trochanter which is difficult to identify precisely in the radiographs

In the frontal plane of the tibia, both CrCd and CdCr radiographs were commensurate with the CT-scan in Pomeranians. Whereas some studies reported the frontal plane angles of the tibia only in the CdCr radiograph (Apelt et al., 2005; Dismukes et al., 2007). This study found the CrCd radiograph rather than the CdCr radiograph of the Chihuahuas' tibia gave the precise values when compared to CT-scan in the normal stifles and in all grades of the MPL stifles. This might be caused by less error during positioning for the CrCd view compared to the CdCr view. According to the study of Apelt et al. (2005), misinterpretation could be made from CdCr radiograph of the tibia because of improper positioning.

The angles in the sagittal plane of radiographs of the tibia (mCdPTA, mCrDTA) were similar to those in the CT-scan in both breeds. In contrast of Toy Poodle, the radiographic measurement of mCdPTA and mCrDTA were incomparable to those in the CT-scan (Yasukawa et al., 2016). The different results might be caused by breed conformational variation of the pelvic limb.

Regarding to the results, taking radiographs of the pelvic limbs of Pomeranians was easier than Chihuahuas. This may be due to Pomeranians have bony conformation straighter than Chihuahuas.

2. **The comparison of angular values between normal and MPL stifles.**

Pelvic limb abnormalities related to MPL have been recently considered because the major complication as postoperative reluxation has been reported. The angular values of the pelvic limb in medium- to large-breed dogs have been focusing.

However, various breed dogs have different conformation of musculoskeletal structures; therefore, the reference values in each breed especially in small-breed dogs which have high incidence of MPL are needed. According to the Hueter-Volkmann principle, immature dogs develop angular deformities due to abnormal force of quadriceps during luxation of the patella against the active physis of the distal femur and proximal tibia. The results indicated that some pelvic limb angles related to MPL in both Chihuahuas and Pomeranians: aLDFA, mLDFA, and FTA. While mMPTA and TTA were related to MPL severity only in Chihuahuas.

In frontal view of distal femoral angles, the relationship between aLDFA and mLDFA with severity of MPL was found. The mean values of both angles in grade 4 MPL were significantly higher than the other grades in these two breeds. These indicate that femoral varus associated with severe MPL (Jackson and Wendelburg, 2012; Soparat et al., 2012; Yasukawa et al., 2016).

For the tibia, the association between severity of MPL and mMPTA was found in Chihuahuas (the mean mMPTA value of grade 4 MPL was significantly higher than those in normal and grade 1-3 MPL). On the contrary, the relationship of MPL with mMPTA was not found in Pomeranians.

The femoral and tibial torsion are illustrated by FTA and TTA, respectively. This study found that both angles have the association with severe MPL in Chihuahuas as well as in Toy-Poodles (Yasukawa et al., 2016). While only FTA had relationship with MPL in Pomeranians. The severity of MPL associated directly to axial plane of the femur in both Chihuahua and Pomeranian. But this is less likely to associate with tibia torsion in Pomeranians since significant differences between grade 4 MPL and the other groups were not found. This might be caused by 1) variation of bone conformation among dogs and 2) age of onset of MPL. Pomeranians with grade 4 MPL in this study had age range between 7 months – 4 years old. If the MPL develops in mature dogs, the deformity would be less likely to occur. Moreover, the MPL is affected by multifactorial causes. Even though external tibial torsion is not found in the pelvic limbs with grade 4 MPL, other deformities of the femur (femoral varus or torsion) or of the tibia (tibial valgus) should be noticed instead.

On the other hand, the following angles were not related with MPL: the frontal plane angles of the proximal femur including aLPFA, mLPFA and ICA; the frontal plane angle of the distal tibia, mMDTA; the sagittal plane angles of the femur including aCdPFA, aCdDFA, PA; the sagittal plane of tibia including mCdPTA and mCrDTA. To our knowledge, the proximal part of the femur and distal tibia, as well as the sagittal plane of the pelvic limbs are not directly affected by abnormal force of quadriceps mechanism during patellar luxation. Moreover, the irrelevance between those angles with MPL has also been reported in Poodle (Yasukawa et al., 2016).

3. The comparison of angular values in three different breeds

As compared among Toy Poodles, Chihuahuas, and Pomeranians, the hindlimb bones of Chihuahuas were shorter than Poodle and Pomeranians in the same proportion. In frontal plane, the femurs and tibias of Chihuahuas were more curve, the head of the femur is larger and the greater trochanter are normally higher than the femoral head. In sagittal plane of femur, high procurvation is noted in Pomeranians. Femoral and tibial conformation of normal Toy Poodle, Pomeranians and Chihuahuas are shown in figures 16-19 and table 12.

Table 12 Means ± SD of the pelvic limb angular values of normal Chihuahuas, Pomeranians and Toy Poodle from CT-scan.

Angles	Chihuahuas	Pomeranians	Toy Poodles[1]
Frontal plane			
aLPFA	123.5±7.4	121.1±4.0	119.5±5.7
mLPFA	119.6±7.5	118.2±3.9	113.6 ± 6.1
aLDFA	96.6±3.7*	97.4±3.3*	90.3 ± 2.8*
mLDFA	100.4±3.2*	100.6±3.4*	96.2 ± 2.5*
ICA	133.3±5.7	133.6±5.5	116.8 ± 6.1
mMPTA	95.6±3.4*	93.3±2.3	94.8 ± 2.1
mMDTA	92.3±6.4	91.3±2.2	96.5 ± 4.1
Sagittal plane			
PA	12.0±3.3	11.3±4.2	11.2 ± 5.2
aCdPFA	159.9±5.8	143.3±5.	153.3 ± 5.1
aCdDFA	106.3±2.8	102.9±2.3	102.9 ± 3.2
mCdPTA	64.6±2.6	66.0±3.1	111.3 ± 3.3
mCrDTA	94.0±3.5	89.9±1.8	98.5 ± 3.8
Transverse plane			
FTA	29.8± 5.6*	33.2±6.8*	19.8 ± 4.6*
TTA	7.1±3.7*	17.64.7	11.3 ± 4.3*

* The angles related to the severity of MPL within each breed. [1] The data from (Yasukawa et al., 2016). aLPFA = anatomical lateral proximal femoral angle; mLPFA mechanical lateral proximal femoral angle, aLDFA = anatomical lateral distal femoral angle, mLDFA = mechanical lateral distal femoral angle; ICA = inclination angle; mMPTA = mechanical medial proximal tibial angle; mMDTA = mechanical medial distal tibial angle. PA = procurvation angle; aCdPFA = anatomical caudal proximal femoral angle; aCdDFA = anatomical caudal distal femoral angles; mCdPTA mechanical caudal proximal tibial angle; mCrDTA = mechanical caudal distal tibial angle; FTA = femoral torsion angle; TTA = tibial torsion angle.

(A) (B) (C)

Figure 16 The femur in frontal plane of Toy poodle (A), Pomeranians (B) and Chihuahuas (C).

(A) (B) (C)

Figure 17 The femur in sagittal plane of Toy poodle (A), Pomeranians (B) and Chihuahuas (C).

(A) (B) (C)

Figure 18 The tibia in frontal plane of Toy poodle (A), Pomeranians (B) and Chihuahuas (C).

(A) (B) (C)

Figure 19 The tibia in sagittal plane of Toy poodle (A), Pomeranians (B) and Chihuahuas (C).

Conclusion

This study found that there are anatomical differences of the pelvic limb among different breeds making the different goniometry values, and presented the goniometry values of Chihuahuas and Pomeranians with normal and MPL stifles. Some angle values have the limitation evaluate by using radiography. Therefore, CT is recommended when the deformity is doubtful.

REFERENCES

Aiken M and Barnes D 2014. Are the fabellae bisected by the femoral cortices in a true craniocaudal pelvic limb radiograph? J. Small Anim. Pract. 55: 465-470.

Alam MR, Lee JI, Kang HS, Kim IS, Park SY, Lee KC and Kim NS 2007. Frequency and distribution of patellar luxation in dogs - 134 cases (2000 to 2005). Vet. Comp. Orthop. Traumatol. 20(1): 59-64.

Apelt D, Kowaleski MP and Dyce J 2005. Comparison of computed tomographic and standard radiographic determination of tibial torsion in the dog. Vet. Surg. 34(5): 457-462.

Aper R, Kowaleski MP, Apelt D, Drost WT and Dyce J 2005. Computed tomographic determination of tibial torsion in the dog. Vet. Radiol. Ultrasound. 46(3): 187-191.

Arthurs GI and Langley-Hobbs SJ 2006. Complications Associated with Corrective Surgery for Patellar Luxation in 109 Dogs. Vet. Surg. 35(6): 559-566.

Bruecker K 2006. Femoral Corrective Osteotomy for the Treatment of Medial Patella Luxation. 14th Annual ESVOT, Munich, Germany.

DeAngelis M and Hohn RB 1970. Evaluation of surgical correction of canine patellar luxation in 142 cases. J. Am. Vet. Med. Assoc. 156: 587-594.

Dismukes DI, Tomlinson JL, Fox DB, Cook JL and Song KJE 2007. Radiographic measurement of the proximal and distal mechanical joint angles in the canine tibia. Vet. Surg. 36(7): 699-704.

Dismukes DI, Tomlinson JL, Fox DB, Cook JL and Witsberger TH 2008. Radiographic measurement of canine tibial angles in the sagittal plane. Vet. Surg. 37: 300-305.

Dudley RM, Kowaleski MP, Drost WT and Dyce J 2006. Radiographic and computed tomographic determination of femoral varus and torsion in the dog. Vet. Radiol. Ultrasound. 47(6): 546-552.

Fox DB and Tomlinson JL 2012. Principles of angular limb deformity correction. In: Veterinary Surgery: Small Animal. ed. KM Tobias and SA Johnston (ed). 3251 Riverport Lane St. Louis, Missouri: Saunder. 657-668.

Gibbons SE, Marcias C, Tonzing M, Pinchbeck GL and Mckee WM 2006. Patellar luxation in 70 large breed dogs. J. Small Anim. Pract. 47: 3-9.

Hayes AG, Boudrieau RJ and Hungerford LL 1994. Frequency and distribution of medial and lateral patellar luxation in dogs: 124 cases (1982-1992). J. Am. Vet. Med. Assoc. 205(5): 716-720.

Hazewinkel HAW, Tellhelm B and Leegwater PA 2013. Screening for Orthopaedic Genetic defects: Part 1. Patella Luxation in Dogs. . European Journal of Companion Animal Practice. 23: 90-98.

Hulse DA 1981. Pathophysiology and management of medial patellar luxation in the dog. Vet. Med. Small Anim. Clin. 76(1): 43-51.

Hulse DA 1993. Medial Patellar luxation in the dog. In: Disease Mechanisms in Small Animal Surgery. Lea&Febiger, Philadelphia.

Jackson GM and Wendelburg KL 2012. Evaluation of the effect of distal femoral elevation on radiographic measurement of the anatomic lateral distal femoral angle. Vet. Surg. 41(8): 994-1001.

Kowaleski MP 2006. Femoral corrective osteotomy for medial patellar luxation. Proceedings of the ACVS Veterinary Symposium, Washington, DC:473-476.

LaFond E, Breur GJ and Austin CC 2002. Breed susceptibility for developmental orthopedic disease in dogs. J Am Anim Hosp Assoc 38: 467-477.

OFA 2015. "Subject: Orthopedic Foundation for Animals: Patellar luxation statistics" (online). Available: http://www.ofa.org/stats_pl.html.

Paley D 2003. Normal Lower Limb Alignment and Joint Orientation. Principle of Deformity Correction. In: Springer-Verlag, Berlin, Germany.

Palmer R 2008. Controversial in the management of patellar luxation. Proceedings of the BVOA Spring Scientific meeting, Birmingham, England:30-34.

Persuki AM, Kowaleski MP, Pozzi A, Dyce J and Johnson KA 2006. Treatment of medial patellar luxation and distal femoral varus by femoral wedge osteotomy in dogs: 30 cases (2000-2005). Proceedings of the 2nd World

Veterinary Orthopedic Congress & 33rd Annual Veterinary Orthopedic Society Conference, Keystone, CO:240.

Petazzoni M 2006. Hind limb alignment in the dog to treat patellar luxation: aretrospective study of 39 cases (2001-2005). 13th Conference of the European Society of Veterinary Orthopaedics and Traumatology, Munich, Germany:263.

Petazzoni M and Jaeger G 2008. Atlas of clinical goniometry and radiographic measurements of the canine pelvic limb. Vol. 2nd. In: Merial, Italia

Piermattei DL, Flo GL and DeCamp CE 2006. The Stifle Joint. In: Handbook of Small Animal Orthopedics and Fracture Repair. fourth ed. (ed). 11830 Westline Industrial Drive, St.Louis, Missouri 63146: Saunders. 562-582.

Priester WA 1972. Sex,size, and breed as risk factors in canine patellar dislocation. J. Am. Vet. Med. Assoc. 160: 740-742.

Roch SP and Gemmill TJ 2008. Treatment of medial patellar luxation by femoral closing wedge ostectomy using a distal femoral plate in four dogs. J. Small Anim. Pract. 49(3): 152-158.

Roush JK 1993. Canine patellar luxation. Vet Clin N Am-Small. 23: 855-868.

Singleton WB 1969. The Surgical Correction of Stifle Deformities in the Dog. J. Small Anim. Pract. 10(2): 59-69.

Slocum B and Slocum TD 2000. Alignment problems of the hindlimb. Pages 60-62 *in* Proceedings of the 10th ESVOT Congress. Munich, Germany.

Soontornvipart K, Wangdee C, Kalpravidh M, Brahmasa A, Sarikaputi M, Temwichitr J, Lavrijsen ICM, Theyse LFH, Leegwater PAJ and Hazewinkel HAW 2013. Incidence and genetic aspects of patellar luxation in Pomeranian dogs in Thailand. Vet. J. 196(1): 122-125.

Soparat C, Wangdee C, Chuthatep S and Kalpravidh M 2012. Radiographic measurement for femoral varus in Pomeranian dogs with and without medial patellar luxation. Veterinary and Comparative Orthopaedics and Traumatology (VCOT). 25(3): 197-201.

Swederski J, Radecki S, Park R and Palmer R 2008. Comparison of radiographic and anatomic femoral varus angle measurements in normal dogs. Vet. Surg. (37): 43-48.

Tomlinson J, Fox D, Cook JL and Keller GG 2007. Measurement of femoral angles in four dog breeds. Vet. Surg. 36(6): 593-598.

Towle HA, Griffon DJ, Thomas MW, Siegel AM, Dunning D and Johnson A 2005. Pre- and postoperative radiographic and computed tomogragphic evaluation of dogs with medial patellar luxation. Vet. Surg. 34: 265-272.

Trotter EJ 1980. Medial Patellar luxation in dog. The Compendium on Continuing Education. 2: 58-66.

Willauer C and Vaseur P 1987. Clinical results of surgical correction of medial luxation of the patella in dogs. Vet. Surg. 16: 31-36.

Yasukawa S, Edamura K, Tanegashima K, Seki M, Teshima K, Asano K, Nakayama T and Hayashi K 2016. Evaluation of bone deformities of the femur, tibia, and patella in Toy Poodles with medial patellar luxation using computed tomography. Vet. Comp. Orthop. Traumatol. 29(1): 29-38.

APPENDIX

Appendix A. The data of sex, age, weight and patella status in 30 Chihuahuas (60 hindlimbs) in total.

Sample No.	Sex	Age (years)	Weight (kg)	Grade of MPL	
				Left	Right
1	F	2	1.9	4	2
2	M	2	3.3	0	0
3	M	4	2.3	2	3
4	M	7	3.2	3	2
5	F	4.75	2.8	3	4
6	M	0.5	2.5	4	4
7	F	1.42	1.6	0	0
8	F	1.08	1.4	3	3
9	F	7.92	2.8	0	1
10	F	6.83	3	0	2
11	F	7.58	3.3	0	2
12	F	3	2.5	1	0
13	M	3	2.3	0	0
14	M	3.42	5	2	3
15	M	1.25	1.8	3	1
16	F	2	3.2	3	3
17	M	1.58	2.3	2	1
18	F	8	4.1	2	2
19	F	1.33	2.4	3	2
20	F	0.58	2.8	3	3
21	F	1.17	3.8	0	1
22	F	3	3	1	1
23	M	3	1	1	1
24	F	1	2.8	2	3
25	F	3	2.2	3	1
26	M	8	3.2	4	4
27	F	0.75	1.1	1	1
28	F	0.75	3.6	1	2
29	F	1	5	4	4
30	M	1.08	2.7	2	0

F- female, M- male.

Appendix B. The data of sex, age, weight and patella status in 36 Pomeranians (60 hindlimbs) in total.

Sample No.	Sex	Age (years)	Weight (kg)	Grade of MPL	
				Left	Right
1	F	0.67	1.2	4	1
2	M	2	3.7	0	1
3	M	1.67	3.6	-	3
4	F	0.83	3.1	4	-
5	F	0.58	2.8	3	2
6	F	1	3.7	2	4
7	F	0.42	7	3	-
8	F	1	4.2	4	4
9	M	3	2.5	3	4
10	M	7	2.4	3	-
11	M	10	3.4	2	2
12	M	0.83	4.1	3	3
13	M	1.5	3.2	2	2
14	M	0.58	2.4	0	2
15	F	1.25	2.5	2	2
16	M	5	3.15	3	-
17	F	0.83	2.3	3	4
18	F	1	1.8	4	-
19	F	1.17	3.6	4	2
20	F	4	4.3	3	4
21	F	0.75	2.9	0	0
22	F	5	2.4	-	1
23	M	2	2.5	0	0
24	M	3	8.1	-	0
25	F	2	2.2	0	1
26	F	1.5	2	0	0
27	F	1.67	2.3	1	1
28	M	0.83	2.5	1	1
29	F	3.25	2.2	0	0
30	M	4	3.1	-	0
31	F	3	3.5	0	0
32	M	5	3	0	0
33	M	1.17	2.7	0	-
34	F	10	2.6	0	0
35	F	1	3.2	0	-
36	M	1.08	3.3	-	0

F- female, M- male.

VITA

Miss Thitaporn Phetkaew was born on March 16th 1988 in Nan, Thailand. She received her Bachelor degree of Doctor of Veterinary Medicine (D.V.M.) from Faculty of Veterinary Medicine, Chiang Mai University in 2012. Her research topic was Comparison of Subcutaneous, Percutaneous Suturing, and Surgical Adhesive Tapes for Skin Closure in Canine Undergoing Ovariohysterectomy. After graduation, she had spent 2 years as a clinician in a private small animal hospital. In 2014, she entered the Master Degree Program in Veterinary Surgery of Chulalongkorn University. Her fields of interest are orthopedic surgery and soft tissue surgery.