MORPHOMETRIC STUDY ON KNEE PARAMETERS VALUES DERIVED FROM MAGNETIC RESONANCE IMAGING SCAN DATA OF PATIENTS WITH KNEE INJURIES

BY

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DECLARATION

This is to certify to the best of my knowledge, this dissertation is entirely the work of the candidate, Mohd Hazim Bin Zulkaflee.

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Introduction : Knee joint is one of the important structures responsible for human locomotion and the commonest joint to suffer from injury in younger population who are active in sports. This study was conducted to perform morphometric evaluation on the knee parameters values derived from MRI scan data of patients presented to Hospital USM with knee injuries.

Objectives : The aims of this study were to find the mean intercondylar notch width (ICW), mean length of posterior cruciate ligament (PCL) and types of intercondylar notch shape in between gender and Malaysian races. Additionally, the relationship between ICW and PCL length and difference in PCL length between types of intercondylar notch shape were identified in the study. Comparison in ICW, PCL length, types of intercondylar notch shape, bicondylar width (BW) and notch width index (NWI) parameters between PCL-injured and non-PCL-injured groups of patients were also done in the study.

Methods : Seventy four MRI images of knee joint obtained from Picture Archiving and Communication System (PACS) Database System of Hospital USM were selected for morphometric analysis. Morphometric measurements of the knee parameters values (ICW, PCL length, Type of intercondylar notch shape, BW, and NWI) were performed using the ‘point to

point measurement' modality of the PAC Universal Viewer software. Next, the data were compared in between the PCL-injured and non-PCL-injured patients to identify the possible differences in between the two groups.

Results : The ICW and PCL length values were higher in male than female gender. Type A intercondylar notch has been recognized as the predominant type in both gender and Malaysian races. ICW has been significantly correlated with PCL length ($p < 0.01$). However, no significant difference was found in the PCL length between types of intercondylar notch shape ($p > 0.0167$). Indeeed, PCL length was noted as the only significantly different parameter between the PCL-injured and non-PCL-injured patients ($p < 0.05$).

Conclusions : These findings might fulfill significant knowledge gap in the knee parameters values of knee joint among the Malaysian population. Furthermore, these findings may help in further discussion of the PCL and its relation to the intercondylar notch structure which is important as one of the etiologies of PCL injury. The orthopedic surgeon may also benefit from the findings of present study in the evaluation of PCL structure before reconstruction surgery.

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TABLE OF CONTENT Page

CHAPTER 1: INTRODUCTION

CHAPTER 2: LITERATURE REVIEW

CHAPTER 3: METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

et.al	And others (Latin: *et alii*)
%	Percentage
MCL	Medial collateral ligament
LCL	Lateral collateral ligament
ACL	Anterior cruciate ligament
PCL	Posterior cruciate ligament
NWI	Notch width index
ICW	Intercondylar notch width
BW	Bicondylar width
mm	Millimeter
MRI	Magnetic resonance imaging
<	Less than
>	More than
p	p-value

°	Degree
IQR	Interquartile range
AL	Anterolateral
PM	Posteromedial
NPV	Negative predictive value
PPV	Positive predictive value
USM	Universiti Sains Malaysia
JEPeM	Jawatankuasa Etika Penyelidikan Manusia
A & E	Accidental and Emergency
PACS	Picture Archiving and Communication Sytem
r	Pearson correlation coefficient
SD	Standard deviation
PPSP	Pusat Pengajian Sains Perubatan
SPSS	Statistical Package for Social Sciences
ICC	Intraclass correlation coefficient
T2W	T2-weighted
TR	Repetition time
TE	Echo time
PDW	Proton density-weighted

ABSTRAK

Kajian Morfometrik ke atas Nilai-nilai Parameter Lutut daripada Data Imbasan Pengimejan Resonan Magnetik Pesakit-pesakit dengan Kecederaan Lutut

Sendi lutut adalah antara struktur penting tubuh yang bertanggungjawab dalam pergerakan manusia dan sendi yang paling kerap mengalami kecederaan dalam golongan muda yang aktif bersukan. Masalah ini dikaitkan dengan struktur sendi lutut yang kompleks dan juga disebabkan oleh trauma tahap tinggi yang dihasilkan akibat kecederaan. Pengimejan resonans magnetik (MRI) telah diiktiraf sebagai modaliti unggul yang digunakan untuk mendiagnosis kes kecederaan lutut kerana keupayaannya dalam menunjukkan konfigurasi anatomi sendi lutut dengan jelas. Satu kajian retrospektif telah dilakukan ke atas data nilai parameter lutut yang diperolehi daripada imbasan imej MRI sendi lutut yang diambil dari Pangkalan Data Sistem Gambar Arkib dan Sistem Komunikasi (PACS) hospital USM. Tujuh puluh empat imej telah dipilih untuk analisis morfometrik. Data berkenaan dianalisis untuk menentukan min lebar takuk

interkondil (ICW), min panjang ligamen krusiat posterior (PCL), jenis-jenis bentuk takuk antara kondil, hubungan antara ICW dan panjang PCL, perbezaan panjang PCL di antara jenis bentuk takuk antara kondil dan untuk membandingkan parameter ICW, panjang PCL, jenis bentuk takuk antara kondil, lebar bikondil (BW) dan indeks lebar takuk (NWI) antara kumpulan pesakit PCL-cedera dan bukan-PCL-cedera. Data demografi imbasan imej MRI mendedahkan bahawa nilai min ICW dan panjang PCL didapati lebih tinggi dalam pesakit lelaki berbanding wanita [ICW: 22.3 (2.48), 19.5 (1.71) dalam lelaki/wanita dan panjang PCL: 39.8 (4.00), 35.9 (3.24) dalam lelaki/wanita masing-masing]. Takuk antara kondil jenis A mempunyai kekerapan tertinggi berdasarkan faktor jantina dan bangsa [jantina: jenis A = 55%, jenis lain = 45% / bangsa: jenis A = 55%, jenis lain = 45%]. Hubungan yang signifikan ditemui di antara ICW dan panjang PCL dengan $p<0.01$. Tiada perbezaan yang signifikan ditemui antara panjang PCL dan jenis bentuk takuk antara kondil dengan $p>0.0167$. Perbandingan nilai parameter lutut antara kumpulan pesakit PCL-cedera dan bukan-PCL-cedera mendedahkan bahawa hanya panjang PCL mempunyai perbezaan yang signifikan antara kumpulan dengan $p<0.05$. Tiada hubungkait yang signifikan ditemui antara jenis bentuk takuk antara kondil dan status kecederaan PCL dengan $p>0.05$. Hasil kajian mungkin dapat memberi manfaat kepada pakar perubatan dan pakar bedah yang terlibat dalam penilaian dan pengurusan kes kecederaan PCL.

ABSTRACT

Morphometric Study on Knee Parameters Values Derived from Magnetic Resonance Scan Data of Patients with Knee Injuries

Knee joint is one of the important structures responsible for human locomotion and the commonest joint to suffer from injury in younger population who are active in sports. This problem is attributed to the complexity of knee joint structures as well as due to high degree of trauma inflicted by the injury. Magnetic resonance imaging (MRI) has been acknowledged as the superior modality used to diagnose cases of knee injury owing to its ability in demonstrating clear anatomical configuration of knee joint. A retrospective study was done on knee parameters values data derived from MRI scan images of knee joint obtained from Picture Archiving and Communication System (PACS) Database System of Hospital USM. Seventy four images were selected for morphometric analysis. The data were analyzed to determine the mean intercondylar notch width (ICW), mean length of posterior cruciate ligament (PCL), types of intercondylar

notch shape, relationship between ICW and PCL length, difference in PCL length between types of intercondylar notch shape and to compare ICW, PCL length, types of intercondylar notch shape, bicondylar width (BW) and notch width index (NWI) parameters between PCL-injured and non-PCL-injured groups of patients. Demographic data of the MRI scan images revealed higher mean value of ICW and PCL length in male than female patients [ICW: 22.3 (2.48), 19.5 (1.71) in male/female and PCL length: 39.8 (4.00), 35.9 (3.24) in male/female respectively]. Type A intercondylar notch has highest frequency based on gender and race factors [gender: type A = 55%, other type = 45% / race: type A = 55%, other type = 45%]. Significant relationship was found between ICW and PCL length with $p<0.01$. No significant difference was found in PCL length between types of intercondylar notch shape with $p>0.0167$. The comparison of knee parameters values between PCL-injured and non-PCL-injured groups of patients revealed that only PCL length was different between the groups with $p<0.05$. No significant association was found between types of intercondylar notch shape and PCL injury status with $p>0.05$. The findings might be beneficial to physicians and surgeons involved in assessment and management of PCL injury cases.

CHAPTER 1
INTRODUCTION

1.1 Overview

The knee joint is a complex structure which is considered as one of the important joints in human body. It is a part of the lower limb joints together with hip and ankle joints which collaborate dynamically in facilitating human locomotion and maintaining static erect posture of human body (Robalo, 2011).

Knee joint has been reported as being the commonest joint to be injured in young population who are active in sports. The reasons why it is more prone to injury and often severe in nature are because of the knee joint structure complexity and vast exposure to high level of forces imparted by sporting activities (Louw *et al.,* 2008). From the gender-specific reports on knee injuries, female have been identified as having higher risk compared to male in acquiring knee injuries. This particular problem can be attributed to several reasons including biomechanical factor such as increased knee valgus angulation, hormonal factor, and neuromuscular factor which is associated with puberty (Louw *et al.,* 2008).

In an epidemiological study of knee injuries among children, Skak *et al.* (1987) reported the knee lesions of various types in children according to age-specific manner in 12 years period of time. They identified the femur metaphyseal fractures as the commonest lesion in young children with median age of 5 years. On the other hand, they found out that ligamentous rupture was associated with low energy trauma and physeal injury was associated with high energy trauma in the teenager group with median age of 12 years (Skak *et al.*, 1987).

Swenson *et al.* (2013) described a detailed epidemiology of knee injuries among US high school athletes during academic session from year 2005/2006 until 2010/2011. They identified that the knee injuries were more common in competition rather than during practice session. The knee injury rate was identified for being highest in football (6.29/10,000 athletes exposure), followed by girls' soccer (4.53) and gymnastic (4.23). Girls have been acknowledged for having higher knee injury rates compared to boys in sports such as soccer, volleyball, basketball, baseball/softball, lacrosse, swimming/diving and track/field (Swenson *et al.*, 2013). The structures of knee joint which commonly affected were medial collateral ligament (MCL) (36.1%), patella/patellar tendon (29.5%), anterior cruciate ligament (ACL) (25.4%), meniscus (23.0%), lateral collateral ligament (LCL) (7.9%), and posterior cruciate ligament (PCL) (2.4%). Furthermore, girls were reported to acquire ACL injuries and treated with surgery more often compared to the boys in gender-comparable sport (Swenson *et al.*, 2013).

Although the rate of PCL injury is lesser compared to the ACL injury, it is reported to occur in about 1% - 40% of acute knee injuries cases (Fanelli *et al.*, 1994). Large magnitude force has been attributed as the cause for PCL injury which is often related with disruption of

other surrounding ligaments (Van Dommelen and Fowler, 1989). In addition to that, three mechanisms have been identified as the causative factors contributing to PCL injury which are hyperextension and hyperflexion of the knee joint and posterior tibial displacement of the femur during knee flexion. The hyperextension of the knee is also known to be linked with the valgus or varus force which can lead to collateral ligament injury (Cross and Powell, 1984; Fanelli *et al.*, 1994).

Schulz *et al.* (2003) reported that the PCL injury is most commonly caused by vehicular trauma particularly motorcycle accident (45%) followed by athletic injuries involving soccer (40%). On top of that, combined PCL injuries (53%) were identified as being commoner than the isolated PCL injuries (47%). Vehicular trauma constituted about 64% of incidence of the combined PCL injuries compared to athletic injuries which constituted about only 46% (Schulz *et al.*, 2003).

There were several studies in the past which focused on the relationship between femoral intercondylar notch and cruciate ligaments injuries. Wada *et al.* (1999) noted that smaller intercondylar notch in patient with osteoarthritic knee does correlated significantly with the ACL tear. Moreover, LaPrade and Burnett (1994) identified higher risk of ACL injuries among athletes having stenotic intercondylar notch. Thus, they would suggest the notchplasty procedure for ACL reconstruction in athletes having the intercondylar notch stenosis for the benefits of reducing the risk of notch impingement on the graft.

Notch width index (NWI) of less than 0.20 in men and less than 0.18 in women has been described by Souryal and Freeman (1993) as having stenotic intercondylar notch. The prevalence

of ACL injury were identified for being as high as 26 times in the stenotic intercondylar notch compared to the normal population (Souryal and Freeman, 1993). On the other hand, Domzalski *et al.* (2010) reported smaller mean value of NWI in the ACL-injured patient compared to the normal population. Thus, they concluded that ACL injury is more liable to occur in the individual having smaller NWI.

Muneta *et al.* (1997) also described the correlation between intercondylar notch width and ligament size. They reported that by having a normal-sized ACL being held in the narrow notches can threaten the ACL structure to injury via impingement of ACL on the smaller margin of the intercondylar notch. Furthermore, van Eck *et al.* (2010) has categorized the femoral intercondylar notch into three types namely the 'A-shaped', 'U-shaped' and 'W-shaped' based on arthroscopic classification. Al-Saeed *et al.* (2012) also reported the type A intercondylar notch as a risk factor for ACL injury.

1.2 Justification of the study

This study was conducted to determine the mean intercondylar notch width (ICW) which could be vital in determining the possibilities of posterior cruciate ligament injuries (Comerford *et al.*, 2006; LaPrade and Burnett, 1994). On top of that, the mean PCL length also can be an important tool in diagnosing chronic PCL injury (Orakzai *et al.*, 2010). This study could help in determining the NWI which can be an indicator whether the intercondylar notch is wide or stenotic in nature which is related to the possibilities of cruciate ligament injuries (Souryal and Freeman, 1993).

The outcome of this study could also help in determining the types of intercondylar notch shape among Malaysian adult population which has been reported as risk factor for ACL rupture as well as important in determining the success rate of ACL reconstruction surgery (Al-Saeed *et al.*, 2012; van Eck *et al.*, 2010). Furthermore, the findings of this study will be beneficial in identifying the possible relationship in between the types of intercondylar notch shape and PCL length which are the risk factors for cruciate ligaments injuries.

Finally, the knee parameters values were compared between the PCL-injured and non-PCL-injured groups of patients to detect any significance difference in between groups which may help in the management of knee injuries.

1.3 Benefit of the study

Parameters value data obtained from this study which includes intercondylar notch width (ICW), bicondylar width (BW) and notch width index (NWI) will be valuable and important for the surgeon and clinicians in diagnosing the stenotic femoral intercondylar notch which is related to cruciate ligaments injuries. Moreover, the diagnosis of chronic PCL injury could be made easier by knowing the mean PCL length which should be equivalent to the mean PCL length of 38 mm as reported by Girgis *et al.* (1975) whereby in case of chronic PCL injury, it appear lax with more lengthening although it looks normal in magnetic resonance imaging (MRI) scan.

On top of that, data on types of intercondylar notch shape could be useful in determining the most vulnerable type that could be related to PCL injury. It could also help in determining the success rate of PCL reconstruction surgery.

Furthermore, the findings from this research, could contribute in the management of knee injury cases particularly involving the cruciate ligaments and the data obtained could also show possible variations among different Malaysian races in the structures of knee joint.

1.4 Study objectives:

1.4.1 General objective

To perform morphometric study on the knee parameters values derived from MRI scan data of patients presented to Hospital USM with knee injuries.

1.4.2 Specific objectives

1. To determine the mean intercondylar notch width in between gender and races.
2. To determine the mean length of posterior cruciate ligament in between gender and races.
3. To identify the types of intercondylar notch shape in between gender and races.
4. To determine the relationship between intercondylar notch width and posterior cruciate ligament length.
5. To determine the difference in posterior cruciate ligament length between the types of intercondylar notch shape.

6. To compare the knee parameters values between PCL-injured and non-PCL-injured patients in term of ICW, BW, PCL length, NWI and types of intercondylar notch shape.

1.5 Research questions

1. Is there a significant difference in mean intercondylar notch width in between gender and races?

2. Is there a significant difference in mean length of posterior cruciate ligament in between gender and races?

3. Is there any difference in types of intercondylar notch shape in between gender and races?

4. Is there a significant relationship between intercondylar notch width and posterior cruciate ligament length?

5. Is there any difference in posterior cruciate ligament length between the types of intercondylar notch shape?

6. Is there any significant difference in knee parameters values between PCL-injured and non-PCL-injured patients in term of ICW, BW, PCL length, NWI and types of intercondylar notch shape?

1.6 Research hypotheses

1. There is no significant difference in mean intercondylar notch width in between gender and races.

2. There is no significant difference in mean length of posterior cruciate ligament in between gender and races.

3. There is no significant difference in type of intercondylar notch in between gender and races.

4. There is no significant relationship between intercondylar notch width and posterior cruciate ligament length.

5. There is no significant difference in posterior cruciate ligament length between the types of intercondylar notch shape.

6. There is no significant difference in the knee parameters values between PCL-injured and non-PCL-injured patients in term of ICW, BW, PCL length, NWI and types of intercondylar notch shape.

1.7 Operational definitions

1. **Intercondylar notch:**

   Deep notch between the posterior surfaces of the medial and lateral epicondyle of the femur, two protrusions on the distal end of the femur (Robalo, 2011)

2. **Magnetic resonance imaging (MRI):**

   Imaging modality that uses a magnetic field and pulses of radio wave energy to map the magnetic behavior of body tissues in a multiplanar reconstructive manner which is non-invasive (Mandelbaum *et al.*, 1986)

3. **Intercondylar notch width (ICW):**

   Width of femoral intercondylar notch which is located in between medial and lateral femoral condyles in axial view of MRI image (Teitz *et al.*, 1997)

4. **Bicondylar width (BW):**

   Width of distal end of femur which extend from medial epicondyle of femur to the lateral epicondyle of femur in axial view of MRI image (Murshed *et al.*, 2004)

5. **Notch width index (NWI):**

   Ratio between the bicondylar width and intercondylar notch width of femur (Souryal *et al.*, 1988)

6. **Posterior cruciate ligament (PCL) length:**

   Total length of PCL from its origin on the lateral aspect of the medial femoral condyle and inserted posterior and inferior to the tibial plateau in sagittal view of MRI image (Orakzai *et al.*, 2010)

CHAPTER 2
LITERATURE REVIEW

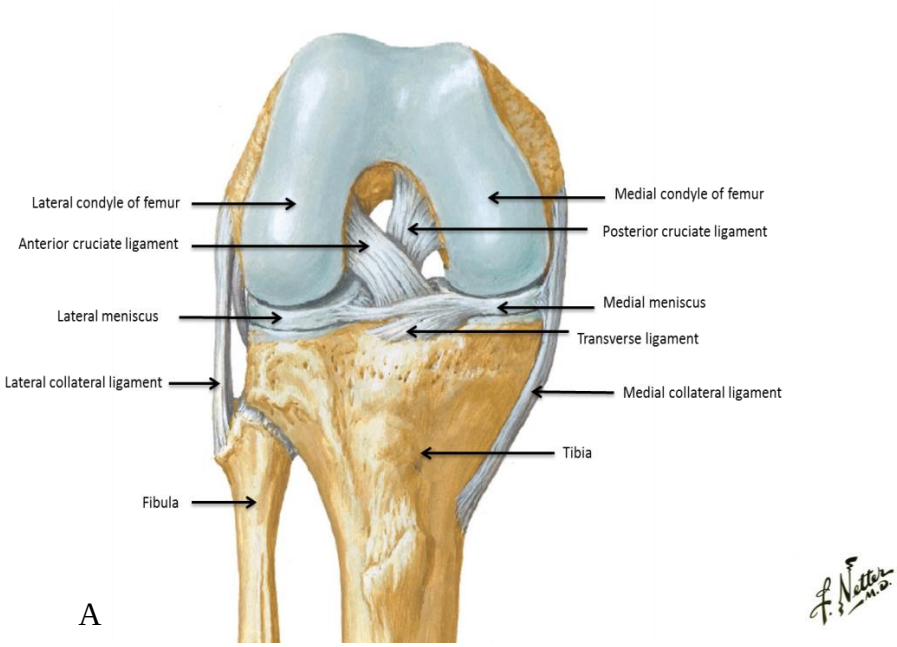
2.1 Anatomy of the knee joint

The knee joint is a highly sophisticated and the largest joint of the body which is made of several structures contained within the synovial cavity of the joint. The structures involved are the tibiofemoral joint which is formed by the femoral and tibial condyles with menisci located in between the condyles together with patellofemoral joint which is located in between the patella bone and patellar surface of femur (Goldblatt and Richmond, 2003; Jenkins *et al.*, 2007).

Tibiofemoral joint is comprised of two condyloid articulations between the femur and tibia bone of the lower limb (Figure 2.1). These articulations are achieved by the interaction of medial and lateral femoral condyles with corresponding tibial condyles which allow flexion and rotational movement as well as providing stability to the knee joint. The lateral femoral condyle is smaller in anterior-posterior and proximal-distal direction compared to medial femoral condyle

which produce anterior-posterior and valgus alignment of the knee (Goldblatt and Richmond, 2003).

The tibial condyles constitute the distal articulating surface of tibiofemoral joint in which the medial and lateral tibial condyles are separated by intercondylar region. This region is characterized by rough area called intercondylar eminence which acts as an attachment point for cruciate ligaments and menici. As the tibial condyles are flat in nature, thus the presence of menisci are important in between the articulating surface of femur and tibia to improve joint congruency and diminish the gap between the two articulating bone surfaces (Robalo, 2011).



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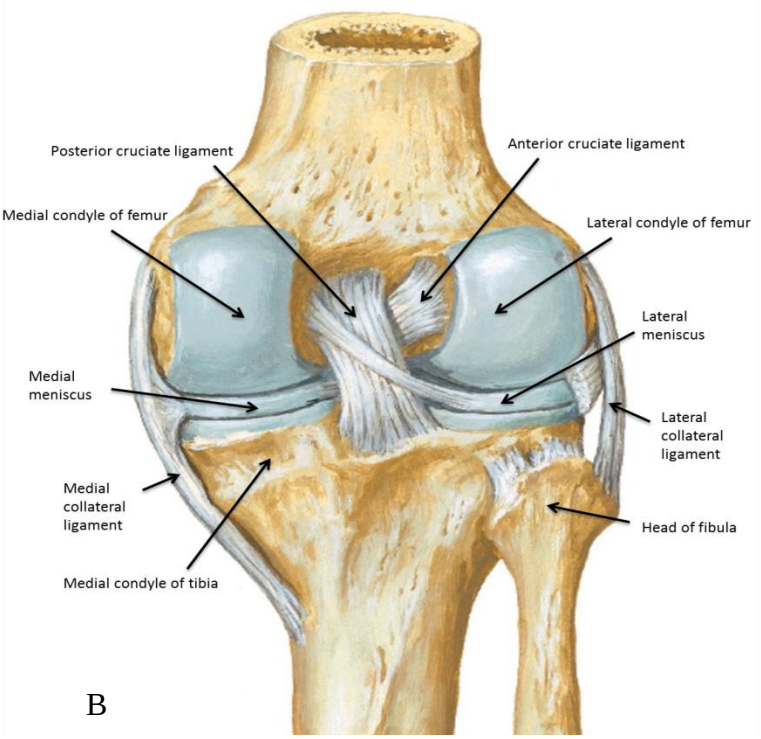


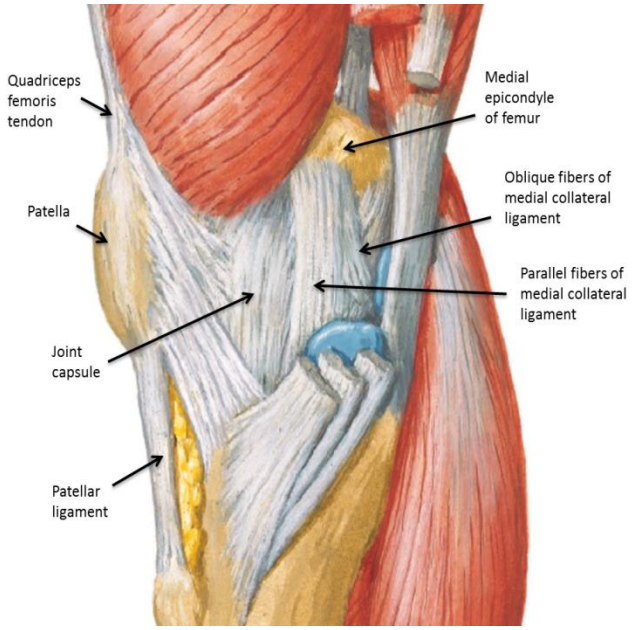
Figure 2.1: Knee joint structures: (A) Anterior view with right knee in flexion (B) Posterior view with right knee in extension. Picture was adopted from Netter (2014)

Patellofemoral joint is another structure which makes up the knee joint of the lower limb. It is a saddle (sellar) joint located in between patella and trochlea of the femur. It is focused on the action of patella which transmit the force produce by extensor muscle across the knee at a greater distance from the rotation axis of the knee which will give positive impact in maintaining knee stability (Goldblatt and Richmond, 2003)

The soft tissue components of the knee joints (Figure 2.1& 2.2) include the ligaments such as anterior cruciate (ACL), posterior cruciate (PCL), lateral collateral (LCL) and medial collateral ligaments (MCL), the lower limb muscles such as quadriceps femoris and popliteus

muscle, the tendons (iliotibial tract), the smooth articular cartilage and the synovial fluid in the knee joint cavity (Robalo, 2011).

Knee joint is a trocho-ginglymos, which means gliding hinge joint based on its kinematic principles which can be described as having rotational, gliding and rolling actions (Hirschmann and Müller, 2015). The movement involves rotational movement which consists of flexion–extension, internal–external and varus–valgus together with translational movement that is possible in anterior–posterior, medial–lateral and also compression-distraction of the knee joint (Gill *et al.*, 2003; Hirschmann and Müller, 2015).



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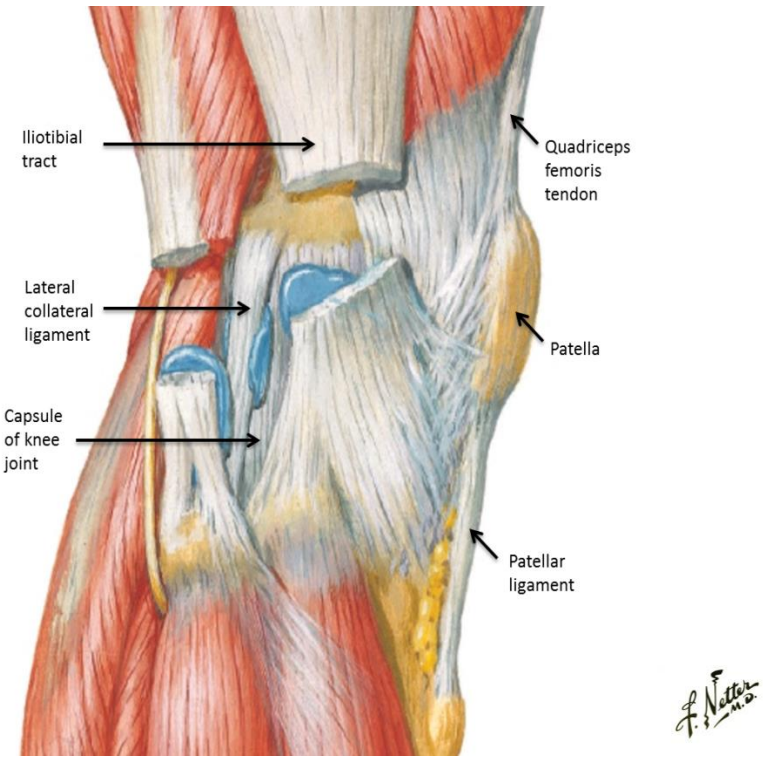

Figure 2.2: Knee joint structures: (A) Medial view of knee (B) Lateral view of knee. Picture was adopted from Netter (2014)

2.2 Studies on femoral intercondylar notch

Femoral intercondylar notch is an area of indentation located between the two condyles of femur which is normally filled with ACL, PCL and fat. The notch is important clinically as narrowed intercondylar notch has been reported as a risk factor for anterior cruciate ligament injury (Comerford *et al.*, 2006). There are several studies in the past which focused on the importance of femoral intercondylar notch from both anatomical and functional point of views.

From the anatomical view, the femoral intercondylar notch has been classified by van Eck *et al.* (2010) into three types which are ‘A-shaped’, ‘U-shaped’ and ‘W-shaped’ based on

arthroscopic classification (Figure 2.2). 'A-shaped' intercondylar notch has been identified as being narrow in every dimensions compared to the other two types which can be a risk factor for ACL injury (Al-Saeed *et al.*, 2012; van Eck *et al.*, 2010) (Table 2.1). However, the association of the types of intercondylar notch shape with the risk of PCL injury has yet to be studied.

In other study, Souryal *et al.* (1988) introduced the notch width index (NWI) measurement which is the ratio between intercondylar notch width and the distal femoral condyle width at the level of popliteal groove in a tunnel view radiograph (Figure 2.4). NWI is an important measurement used in comparing intercondylar notch width on plain radiographs.

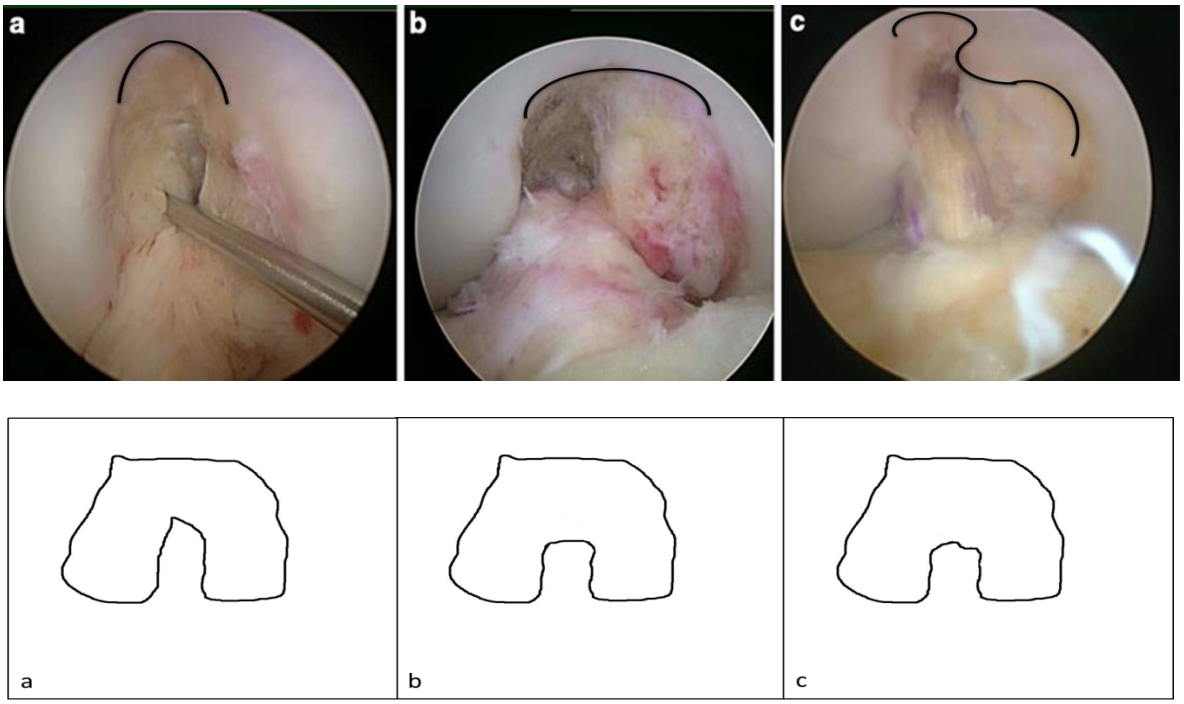

Figure 2.3: Classifications of femoral intercondylar notch into three types based on arthroscopic classification which are, a: 'A-shaped', b: 'U-shaped', c: 'W-shaped'. Photograph was adopted from van Eck *et al.* (2010)

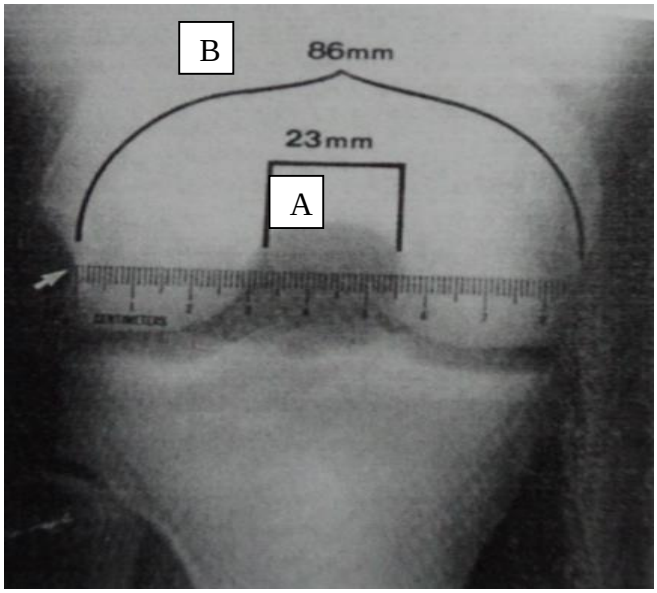

Figure 2.4: NWI measurement in a tunnel view radiograph: A / B, A- Intercondylar notch width (ICW), B- Bicondylar witdh (BW), NWI- Notch width index. Picture adapted from Souryal *et al.* (1988)

Table 2.1 Frequency of the types of intercondylar notch in anterior cruciate ligament-injured patients

Type of intercondylar notch	van Eck et al. (2010) N = 102	Al-Saeed et al. (2012) N = 280
A-shaped	55 (53.9%)	176 (62.9%)
U-shaped	42 (41.1%)	100 (35.7%)
W-shaped	5 (4.9%)	4 (1.4%)

Furthermore, the stenotic intercondylar notch was described by Souryal and Freeman (1993) as having the NWI of less than 0.20 in men and less than 0.18 in women (Figure 2.5). They also noticed the prevalence of ACL injury for being as high as 26 times in the stenotic intercondylar notch compared to the normal sized intercondylar notch. This statement is supported by Wada *et al.* (1999) based on the study of the femoral intercondylar notch measurements in osteoarthritic knee. They proclaimed that smaller intercondylar notch does have a significant relationship with ACL tear in the osteoarthritic knee. Moreover, LaPrade and Burnett (1994) proved significant correlation between stenotic femoral intercondylar notch and ACL injuries in which they identified higher risk of ACL injuries among athletes having stenotic intercondylar notch. However, there are no previous studies which show the relationship between the stenotic intercondylar notch and PCL injuries.

In a comparative study on the canine ACL structure and its relation to distal femoral intercondylar notch by Comerford *et al.* (2006), they identified that the narrow notch width index (NWI) is causing the impingement of ACL on surrounding structure that can lead to ACL rupture ultimately. Meanwhile, Domzalski *et al.* (2010) also reported smaller mean value of NWI in the ACL-injured patients (0.2438) compared to the control population (0.2641) ($p < 0.001$) which is associated with higher risk for ACL rupture in the skeletally immature population. Thus, the findings by Comerford *et al.* (2006) and Domzalski *et al.* (2010) suggested that the NWI value might be different in between the ACL-injured and non-ACL-injured patients. On the contrary, Teitz *et al.* (1997) reported no significant difference between the mean NWI of patients with ACL injury (0.248) and

Figure 2.5: Differences in the size of femoral intercondylar notch in between male and female. Picture adopted from **http://www.hughston.com/hha/a_14_4_2.htm**

without ACL injury (0.253) ($p= 0.53$). Alizadeh and Kiavash (2008) also reported no significant difference in NWI of patients with (0.296) and without (0.298) ACL tear ($p= 0.873$). Likewise, the findings by Teitz *et al.* (1997) and Alizadeh and Kiavash (2008) suggested no differences in NWI value of the ACL-injured and non-ACL-injured patients (Table 2.3). In spite of that, the differences in NWI value in between the PCL-injured and non-PCL-injured patients yet to be identified.

Based on the analysis of the intercondylar notch width (ICW) for identification of risk factors for ACL injury in skeletally immature patient, Domzalski *et al.* (2010) reported significant difference ($p< 0.001$) in the mean ICW value between ACL-injured (24.15 mm) and normal knees (26.91 mm). These findings supported the finding by Park *et al.* (2012) whom identified smaller ICW in ACL-injured (17.37 mm) compared to non-ACL-injured male patients (20.33 mm). These findings were also the same in female patients which have smaller ICW in

ACL-injured (15.76 mm) compared to non-ACL-injured patients (18.52 mm) (Park *et al.*, 2012). Both findings by Domzalski *et al.* (2010) and Park *et al.* (2012) suggested differences in the ICW values between the ACL-injured and non-ACL-injured patients (Table 2.2). Even so, the differences in ICW value in case of PCL-injured and non-PCL-injured patients have yet to be proven.

Table 2.2 Difference of intercondylar notch width among patients with and without anterior cruciate ligament injury

	Domzalski et al. (2010)	Park et al. (2012)
Anterior cruciate ligament-injured	24.15	Male : 17.37 Female : 15.76
Anterior cruciate ligament-not injured	26.91	Male : 20.33 Female : 18.52

Table 2.3 Difference of notch width index among patients with and without anterior cruciate ligament injury

	Teitz et al. (1997)*	Alizadeh and Kiavash (2008)*	Domzalski et al. (2010)

Anterior cruciate ligament-injured	0.248	0.296	0.2438
Anterior cruciate ligament-not injured	0.253	0.298	0.2641

Not significant*

2.3 Studies on posterior cruciate ligament

In these recent years, many studies have been conducted on the anatomy and biomechanics of the PCL (Amis *et al.*, 2006; Bowman and Sekiya, 2009; Kweon, 2013). The studies mainly accredited to the increasing interest in PCL. It has been related to increase incidence of PCL injuries although the injuries might be only occasionally noticed compared to ACL injuries.

PCL being the stronger cruciate ligament compared to ACL extend from broad area on lateral aspect of medial femoral condyle and projects to a sulcus located posterior and inferior to the tibia articular plateau (Kweon, 2013).Girgis *et al.* (1975) were among the pioneer researchers who did an extensive study on the anatomical structure of the PCL in order to achieve a better understanding of its function as well as to enhance the method in diagnosing and dealing with PCL injuries. They described that the PCL has average length of 38 mm and average width of 13

mm. In other study, Dargel *et al.* (2009) reported no significant differences in the length of PCL between the right [35.4 mm (4.5)] and left [34.3 mm (4.1)] knees with statistically significant correlation (r = 0.599) in between them. On top of that, Orakzai *et al.* (2010) stated that ratio of the lateral femoral condylar width to the PCL length in the sagittal plane of MRI is important in diagnosing the chronically injured PCL which become attenuated in a lengthening condition despite of normal MRI appearances. Hence, the present study attempts to identify the differences in PCL length between PCL-injured and non-PCL-injured patients.

Van Dommelen and Fowler (1989) described the PCL as an extra-articular structure even though it is enclosed in synovium in which the synovium originated from posterior capsule and overlaying the ligament on its medial, lateral and anterior aspects. Next, Goldblatt and Richmond (2003) described the PCL as being extended in between

femur and tibia bone via the respective femoral and tibial attachments (Figure 2.6). Femoral attachment of the PCL is at the lateral surface of medial femoral condyle while the tibial attachment of PCL is at the depressed area between the two tibial plateaus behind the articular surface of tibia.

Bowman and Sekiya (2009) described the PCL as being made of two closely related bands namely the anterolateral (AL) and posteromedial (PM) band of which their morphology are closely related to the action of the knee joint (Figure 2.7). The AL band is becoming taut as flexion of the knee increases above 30° meanwhile the PM band become taut as the knee is being extended (Bowman and Sekiya, 2009; Goldblatt and Richmond, 2003).

Subsequently, PCL has been acknowledged as the primary restraint to posterior tibial translation at all knee flexion angles > 30° (Fanelli *et al.*, 1994; Hirschmann and Müller, 2015; Van Dommelen and Fowler, 1989). They also function as secondary restraint against excessive varus-valgus angulation of the knee and external tibial rotation (Bowman and Sekiya, 2009; Goldblatt and Richmond, 2003). AL band of the PCL is vital in resisting posterior tibial translation in 70°-90° of knee flexion meanwhile PM band of the PCL helps in resisting posterior tibial translation in knee extension (Kweon, 2013).

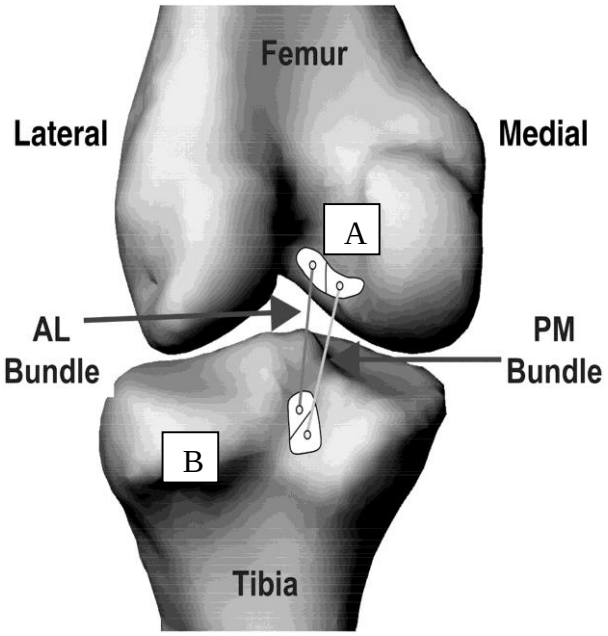

Figure 2.6: Femoral and tibial attachments of the PCL. A: Femoral attachment: Lateral surface of medial femoral condyle, B: Tibial attachment: Depressed area between the two tibial plateaus. PCL- Posterior cruciate ligament. Picture adapted from Papannagari *et al.* (2007)

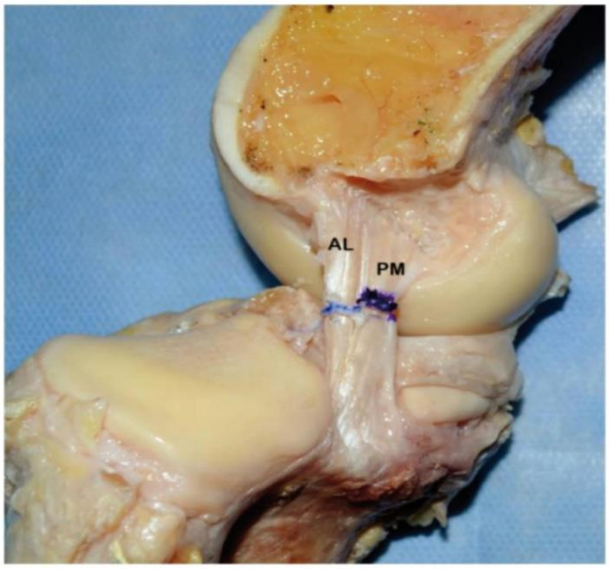

Figure 2.7: Anterolateral and posteromedial band of PCL. AL- Anterolateral, PM- Posteromedial, PCL- Posterior cruciate ligament. Picture adapted from Gali *et al.* (2013)

2.4 Knee Injury prevalence and distribution

Knee injuries especially with regards to cruciate ligament injuries have been reported by many authors since there is increased in involvements in high risk sport activities regardless of the gender (Bollen, 2000; De Loes *et al.*, 2000; Ingram *et al.*, 2008; Majewski *et al.*, 2006).

Majewski *et al.* (2006) did an epidemiological study based on the athletic knee injuries over a 10-year period. They reported higher incidence of knee joint injuries in male (68.1%) compared to female (31.6%). The incidences are highest in the age group of 20-29 years old (43.1%) followed by the age group of 30-39 years old (20.9%).The ACL lesion is identified to have the highest prevalence (20.3%) in contrast to the PCL lesion which has the lowest prevalence (0.65%) among other knee lesions (Majewski *et al.*, 2006).

Myklebust *et al.* (1997) did a prospective study on identifying the prevalence of cruciate ligament injuries and possible gender differences in the high level Norwegian team handball. They reported 87 ACL injuries and 6 PCL injuries in all three divisions of the handball team with 63% of the injuries occurring in females (54 ACL injuries and 5 PCL injuries) which are higher compared to only 37% of injuries in males (33 ACL injuries and 1 PCL injury).

Besides that, De Loes *et al.* (2000) did a 7-year extensive study on the risk and cost of medical treatment for knee injuries in youth participants aged from 14-20 years in 12 sports activities. They reported higher risk of injuries among female in six sports namely alpinism, downhill skiing, gymnastic, volleyball, basketball, and team handball. The knee injuries also responsible for 13% of all injuries in female compared to only 10% in male.

An organized review on the epidemiology of knee injury among active adolescents aged 13-19 years old have been conducted by Louw *et al.* (2008) to identify the prevalence and risk factors contributing to the knee injuries among adolescents. They found out that the knee injuries seem to be a common manifestation among female compared to male adolescent sport participant.

After all, the finding by Louw *et al.* (2008) would support the findings by Myklebust *et al.* (1997) and De Loes *et al.* (2000) whom reported higher female susceptibility to knee injuries compared to male. The present study would identify the prevalence of knee injuries particularly involving the PCL among genders and races.