THE CORRELATION OF THE MORPHOLOGY OF THE MEDIAL PATELLOFEMORAL LIGAMENT (MPFL) WITH THE DIMENSIONS OF THE PATELLA, THE PATELLAR TENDON, THE Q-ANGLE AND FEMORAL TROCHLEAR GROOVE

By

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DECLARATION OF ORIGINAL WORK

I hereby declare that the compilation of this master's dissertation submitted here is the result of my own independent work and that all the sources I have used or quoted have been indicated and acknowledged by means of complete references. I have also acknowledged those persons who assisted me in this endeavour. I further declare that this dissertation is submitted for the first time at the University of the Free State for the purpose of obtaining a Master's degree in Anatomy and Cell Morphology and that it has never been submitted to any other university/faculty.

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SUMMARY

The medial patellofemoral ligament (MPFL) is an essential contributing component to a stable patellofemoral joint (PFJ). The PFJ is a complex structure that has balanced forces acting on the stable joint. The aim of this study was to correlate the morphology of the MPFL with the Q-angle, the patellar tendon, the patella and the femoral trochlear groove (FTG) in a stable PFJ.

Thirty-four cadaver knees were dissected. The Q-angle for each knee was measured with a goniometer. Dimensions of the MPFL, patella and patellar tendon were measured with a Vernier calliper. The femoral trochlear groove was photographed and photometrically measured with the use of the computer program *ImageJ*. The data collected were statistically analysed to determine Spearman's Rank correlations coefficient (r_s). A correlation coefficient of r_s= 0.482 was considered significant.

Firstly, it was found that the length of the MPFL correlated with eleven other measurements. These correlations include the proximal width of the patellar tendon; the length of the patellar tendon; the medial facet width of the patella; the articulating height of the patella; the osseous length of the patella; all the osseous measurements of the FTG; and the mathematically-derived depth of the FTG. Secondly, eight correlations were found with the femoral attachment width of the MPFL. These correlations include both the proximal and distal widths of the patellar tendon; the osseous length and width of the patella; the lateral patellar groove width of the FTG; both the medial and lateral altitudes of the FTG; and the altitude of the deepest point of the FTG. Lastly, the width of the attachment of the MPFL to the vastus intermedius tendon only correlated with the length of the patellar tendon.

The morphology of the MPFL positively correlated with specific measurements of the patella, patellar tendon and the FTG in a stable PFJ. This may be explained by the gradual increase in size of the structures in the joint. The findings suggest that the MPFL forms part of a harmonious interplay and disrupting this balance, either by pathology or reconstructive surgery, may alter the delicate harmony in the joint.

Keywords: Medial Patellofemoral Ligament, Stability, Patellofemoral Joint, Patella, Patellar Tendon, Q-angle, Femoral Trochlear Groove, Spearman's Ranked Correlation Coefficient.

OPSOMMING

Die mediale patellofemorale ligament (MPFL) is ’n noodsaaklike bydraende faktor tot ’n stabiele patellofemorale gewrig (PFG). Die PFG is ’n komplekse struktuur met gebalanseerde kragte wat saamwerk tot ’n stabiele gewrig. Die doel van hierdie studie was om die morfologie van die MPFL te korreleer met die Q-hoek, die patellêre tendon, die patella en die femorale trogleêre groef (FTG) in ’n stabiele PFG.

Vier-en-dertig kadawerknieë is gedissekteer. Die Q-hoek van elke knie is gemeet met ’n goniometer. Afmetings van die MPFL, patella en patellêre tendon is gemeet met ’n Vernier skuifpasser. Die femorale trogleêre groef is gefotografeer en fotometries gemeet met die rekenaarprogram *ImageJ*. Die data versamel is statisties geanaliseer om die Spearman Rangkorrelasie koëffisiënt (r_s) te bepaal. ’n Korrelasie koëffisiënt van r_s = 0.482 is as beduidend beskou.

Eerstens het die lengte van die MPFL gekorreleer met elf ander afmetings. Hierdie korrelasies sluit in die proksimale wydte van die patellêre tendon; die lengte van die patellêre tendon; die mediale faset-wydte van die patella; die artikulerende hoogte van die patella, die ossale lengte van die patella; al die osseuse afmetings van die FTG; en die wiskundig afgeleide diepte van die FTG. Tweedens is agt korrelasies gevind met die femorale hegtingswydte van die MPFL. Hierdie korrelasies sluit in beide die proksimale en distale wydtes van die patellêre tendon; die ossale lengte en wydte van die patella; die laterale patellêre groefwydte van die FTG, beide die mediale en laterale lengtes van die FTG; en die hoogte van die diepste punt op die FTG. Laastens het die wydte van die hegting van die MPFL tot die vastus intermedius tendon slegs met die lengte van die patellêre tendon gekorreleer.

Die morfologie van die MPFL het positief gekorreleer met spesifieke afmetings van die patella, patellêre tendon en die FTG in ’n stabiele PFG. Dit kan moontlik verduidelik word deur die geleidelike toename in die grootte van strukture in die gewrig. Die bevindinge blyk daarop te dui dat die MPFL deel uitmaak van ’n interne harmonieuse wisselwerking en dat die ontwrigting van hierdie balans, hetsy deur patologie of rekonstruktiewe chirurgie, die delikate balans in die gewrig mag ontwrig.

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LIST OF ABBREVIATIONS

ADP	Altitude of the Deepest Point of the femoral trochlear groove
ALM	Altitude of Lateral Margin of the lateral condyle of the femur
AMM	Altitude of Medial Margin of the medial condyle of the femur
ASHP	Articulating Surface Height of the Patella
ASIS	Anterior Superior Iliac Spine
CP	Centre of the Patella
DFTG	Depth of the Femoral Trochlear Groove
DPTW	Distal Patellar Tendon Width
FTG	Femoral Trochlear Groove
LFGW	Lateral Patellar Groove Width of the FTG
LFWP	Lateral Facet Width of the Patella
MFGW	Medial Patellar Groove Width of the FTG
MFWP	Medial Facet Width of the Patella
MPFL	Medial Patellofemoral Ligament
MPFLF	Femoral attachment width of the MPFL
MPFLL	Length of the MPFL
MPFLM	Width in the Middle of the MPFL
MPFLP	Proximal attachment width of the MPFL
MPFLVI	Width of attachment of the MPFL to the tendon of vastus intermedius muscle
MRI	Magnetic Resonance Imaging
OLP	Osseous Length of the Patella
OWP	Osseous Width of the Patella
PFJ	Patellofemoral Joint
PPTW	Proximal Patellar Tendon Width

PTL	Patellar Tendon Length
Q-angle	Quadriceps angle
r_s	Spearman's Ranked Correlation Coefficient
TGA	Trochlear Groove Asymmetry
TT	Tibial Tuberosity
VMO	Vastus Medialis Oblique Muscle

Chapter 1

ORIENTATION OF THE STUDY

1.1 INTRODUCTION

This study focused on the analysis of the correlations between the main medial static stabiliser of the patella, the Medial Patellofemoral Ligament (MPFL), and other structures in the patellofemoral joint (PFJ) that contribute to stability. These structures that contribute collectively with the MPFL towards stability include the Quadriceps -angle (Q-angle), specific morphological features of the patella, the patellar tendon and the geometry of the femoral trochlear groove (FTG) in knees with a stable PFJ.

Stability of the PFJ is important, since instability may be a major cause of anterior knee pain and may ultimately lead to subluxation and/or lateral dislocation of the patella.[1] Stability is defined as resistance to displacement away from the stable position of equilibrium where all forces are in balance.[2] Stability of the PFJ is effected by a harmonious interplay of osseous components and the soft tissue structures of the joint. The osseous components consist of the trochlea of the femur and the patella.[2] The extensor mechanisms are the soft tissue elements that contribute towards the stability of the PFJ.[3]

The MPFL contributes approximately 50% to the stability of the PFJ against lateral patellar dislocation.[4] Similar results were found by Desio, Burks and Bachus[5] (60%) as well as Conlan, Garth and Lemons[6] (53%). It was therefore concluded that the MPFL is the main static medial soft tissue restraint to lateral patellar dislocation.[4–6]

Additional factors that contribute towards the stability of the PFJ include the Q-angle, the patellar tendon, the patellar morphology and the geometry of the FTG.[2]

1.2 BACKGROUND TO THE RESEARCH PROBLEM

Various osseous and soft tissue components contribute towards the stability of the PFJ functions in a harmonious balance. Disturbance of the dynamic harmony may alter the PFJ contact pressures[2], which in turn may lead to PFJ pathology.

The PFJ is a complex structure with different forces acting on the joint. Understanding the anatomy of the PFJ is essential for understanding the pathologies that may affect it.[7–9] Knowledge of the anatomical correlations may significantly contribute to the general understanding of the PFJ, since correlation studies regarding the MPFL, the Q-angle, the patella, the patellar tendon and the FTG have only been done to a lesser extent.

1.3 PROBLEM STATEMENT

The PFJ is dynamic in nature and consists of several soft tissue and osseous structures. These different elements of the PFJ in the normal knee joint are in a harmonious balance in a stable PFJ. The MPFL is the main medial static stabiliser of the PFJ. The MPFL has several variations regarding the attachments of the ligament, the length of the ligament and its width in a stable PFJ. It is not yet known how these morphologic variations correlate with other elements of the PFJ that also contribute towards stability.

1.4 OVERALL GOAL OF THE STUDY

The overall goal of this study was to measure and correlate the various structures of the stable PFJ. For the purpose of this study these structures included the Q-angle, the patellar tendon, the patella, the MPFL and the FTG. The data collected was then analysed by a biostatistician and interpreted by the researcher, ultimately describing the correlations found between the morphology of the MPFL and these other structures.

1.5 AIM OF THE STUDY

This study aimed at observing, measuring and correlating certain anatomical variations of the osseous components and soft tissue structures in the stable PFJ. The data collected were correlated with the morphology of the MPFL to determine how the morphometry of this ligament changes in relation to the other structures in the PFJ that contribute to stability.

1.6 OBJECTIVES OF THIS STUDY

The objectives of this study are intended to remedy the problem statement. The objectives are as follows:

The first objective was to determine the Q-angle; to dissect, measure and describe the morphology of the MPFL, patellar tendon, patella and FTG.

The second objective of this study applied Spearman's ranked correlation coefficient to determine the relationship between the morphology of the MPFL and the Q-angle, patellar tendon, patella and the FTG.

1.7 RESEARCH DESIGN OF THE STUDY

The study was an observational descriptive quantitative study. The study population consisted of male and female adult cadavers with a minimum age of 18.

Descriptive statistics, namely means and standard deviations or medians and percentiles, were calculated for continuous data. Frequencies and percentages were calculated for the categorical data.

Within group changes were evaluated using appropriate tests and confidence intervals for paired data. Statistical analysis of the analytical data were performed by the Department of Biostatistics of the UFS.

Spearman's ranked correlation coefficient was used to determine the correlations between the parameters.

1.8 DEMARCATION OF THE FIELD AND SCOPE OF THE STUDY

This study included male and female cadavers from the Department of Basic Medical Sciences in the School of Medicine in the Faculty of Health Sciences at the University of the Free State. This study only included anatomical normal knees without any visible signs of pathology or surgery present. The collection of the data commenced in 2015 after approval from the various committees and the head of the department of Basic Medical Sciences. These committees included the Evaluation Committee and the Faculty of Health Research Ethical Committee of the University of the Free State (Appendix A).

This study focused on the morphology of the MPFL and other structures in the PFJ from a human anatomy perspective.

1.9 THE SIGNIFICANCE OF THIS STUDY

The outcome of this study will describe the morphology of the MPFL and correlations of the MPFL with the Q-angle, the patellar tendon, the patella, and the geometry of the femoral trochlear groove. The description of correlations in the knee will further contribute to the knowledge base with regard to PFJ stability and treatment of patellar instability. This may lead to a deeper understanding of the influence of the MPFL, the Q-angle, the patellar tendon and the patella on the PFJ.

The morphology of the MPFL will be more clearly understood, with regard to extensions of the MPFL. This will also assist surgeons in the interpretation of magnetic resonance imaging.

1.10 IMPLEMENTATION OF THE FINDINGS

The findings of this study will contribute towards the field of orthopaedic surgery, with the focus on reconstructive surgery of the MPFL. The morphology of the MPFL will be more clearly understood, especially with regard to extensions of the MPFL. The findings will also clinically assist surgeons with the interpretation of magnetic resonance imaging.

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

The medial patellofemoral ligament (MPFL) has been found to significantly contribute towards the stability of the patellofemoral joint (PFJ).[4–6] Stability of the PFJ is created by a harmonious interplay of osseous and soft tissue structures.[2] The osseous components include the patella and the femoral trochlear groove, whereas the soft tissue structures are referred to as the extensor mechanism of the PFJ.[1,10] The anatomy of the PFJ suggest that during full extension only soft tissue structures prevent lateral patellar displacement.[11] The MPFL contributes up to 60% of the resistance to prevent lateral patellar dislocation.[4–6] It is imperative to understand how the different structures that contribute to stability of the PFJ relate to the main medial static stabiliser, the MPFL.

2.2 THE PATELLOFEMORAL JOINT (PFJ)

The PFJ forms part of the most composite joint in the body, the knee joint.[12] During flexion of the knee joint, the patella glides from the proximal to the distal part of the femoral trochlea in the PFJ. The stability of the PFJ is maintained by various aspects that include anatomical structures and dynamics working together in harmony with each other.[2] These aspects include the joint geometry, limb alignment, retinacula and muscles.[2] When the PFJ moves from extension to flexion and vice versa, the patella is guided by the extensor mechanism.[1] The extensor mechanism stabilises the patella in a cruciform manner (Figure 2.1). The extensor mechanism includes the so-called static and dynamic stabilisers.[1,10] Dynamic stabilisers include the quadriceps muscles, whereas the static stabilisers include the patellar tendon, the quadriceps tendon, the medial and lateral retinacula.[1]

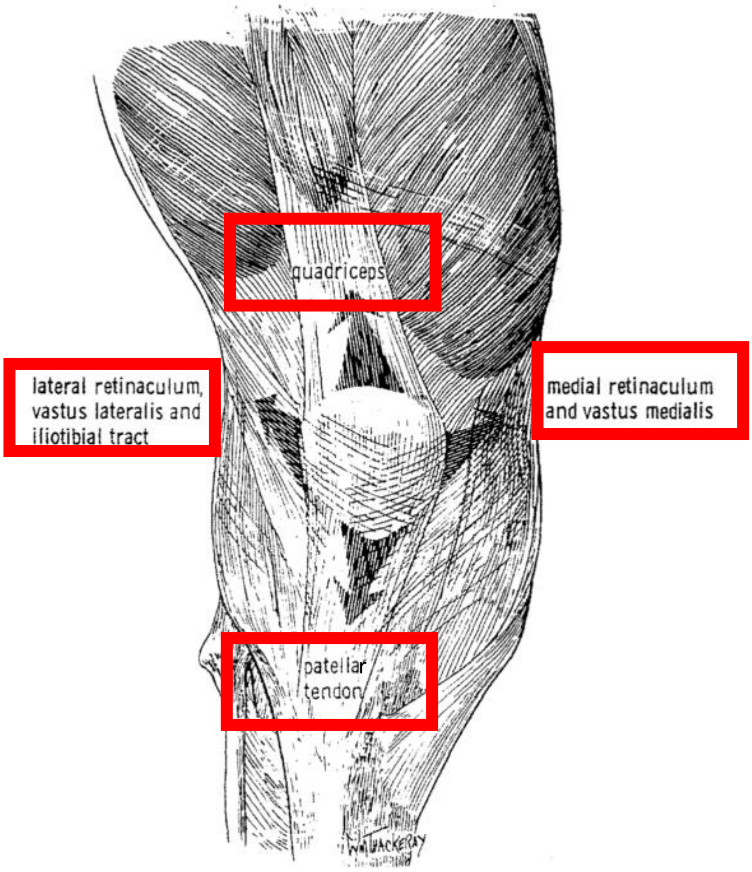

Figure 2.1: The extensor mechanism of the PFJ, stabilising the patella in a cruciform manner. This image was adapted from Elliott and Diduch.[1]

The retinaculum is a collective term used to include all the structures along the anteromedial and anterolateral border of the patella.[1,13] The lateral retinaculum of the knee includes the deep fascia of the thigh, derivatives of the iliotibial band, quadriceps aponeurosis, and the knee joint capsule.[14] The knee joint capsule thickens laterally to form the lateral patellofemoral and patellomeniscal ligaments.[14] According to Warren and Marshall[15] the soft tissues on the medial side of the knee are organised into three layers. The first layer consists of the superficial and deep fascia. The second layer includes several ligaments: the superficial medial collateral ligament, the medial patellotibial ligament and the MPFL. Layer three consists of the capsule of the knee joint.[15] The MPFL is a definite clinical entity, separate from the knee joint capsule and is consistently found in layer two, with the medial collateral ligament.[6,16,17]

During full extension, as the patella disengages the trochlea, only soft tissue structures prevent lateral patellar displacement.[11] In the terminal phase of extension, the patella disengages the trochlea and only engages it again in an anatomical lateral to medial fashion at approximately 15 to 20 degrees of flexion.[13,18]

Stability of the PFJ is important, since instability may be a major cause of anterior knee pain and may ultimately lead to subluxation and/or lateral dislocation of the patella.[1] Stability is defined as the resistance to displacement away from the stable position of equilibrium where all the forces are in balance.[2] The MPFL provides up to 60% of the stability of the PFJ.[5] This was confirmed by both Panagiotopoulos *et al.*[4] (50%) and Conlan *et al.*[6] (53%). It was therefore concluded that the MPFL is the main static medial soft tissue restraint to lateral patellar dislocation.[4–6] Additional factors that have an influence on the stability of the PFJ include the quadriceps vector force (Q-angle), patellar tendon morphology, patellar morphology and the geometry of the FTG.[2]

The different osseous and soft tissue components which contribute toward the stability of the PFJ function in a harmonious balance in a stable PFJ. Disturbance of the dynamic harmony may alter the PFJ contact pressures, which in turn may lead to PFJ pathology.[2]

2.3 THE QUADRICEPS ANGLE (Q-ANGLE)

The lower limb of the human body has a hip-knee-ankle angle.[19] This angle may either be interpreted as a valgus or varus angle in healthy asymptomatic subjects.[19] Within the extensor mechanism, the quadriceps resultant force, the patella and the patellar tendon, will form a valgus angle, hereafter referred to as the Q-angle (Figure 2.2).[20]

The Q-angle was first defined by Brattström[20] as an angle formed between the patellar tendon and the extension of a line formed by the quadriceps muscles resultant force with its apex at the patella. More recently, this angle has been described as the angle between a line connecting the anterior superior iliac spine with the centre of the patella and the extension of a line connecting the tibial tuberosity with the centre of the patella.[21–23]

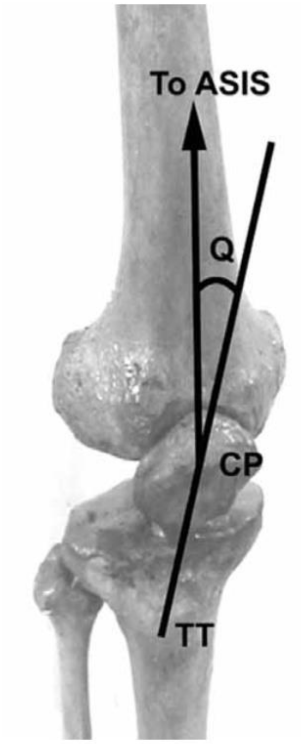

Figure 2.2: The quadriceps angle (Q-angle). The landmarks of the Q-angle include the ASIS (Anterior Superior Iliac Spine), CP (Centre of Patella), and TT (Tibial Tuberosity). This image was taken from Veeramani Raveendranath, Sujatha, Priya and Rema.[24]

The Q-angle is an indication of the direction of the lateral force on the patella. During flexion of the knee, the retropatellar force vector of the patella against the trochlea of the femur increases as the knee reaches full flexion.[2] The opposite is also true: when the knee extends, the retropatellar force vector of the patella against the trochlea of the femur decreases as the knee reaches full extension.[2] In the terminal phase of knee extension, the external rotation of the tibia, the so-called “screw-home mechanism”, advances the tibial tuberosity more laterally[18]. This subsequently increases the Q-angle. When the quadriceps muscles are in full isometric contraction, the tibia externally rotates and the patella disengages from the trochlea of the femur. The lateral Q-angle force vector on the patella is now at its maximum.[2]

The Q-angle represents the force vector of the quadriceps muscles on the patella in the frontal plane.[25] Several different measuring protocols exist to determine the Q-angle.[22] Extant literature suggests that several factors can influence the measurement of the Q-angle.[21,26] These factors include the maximal isometric contraction and relaxation of the quadriceps muscles; the foot positions of the subject; supine and standing position, and the measurement instruments.[21,26] Insall *et al.*[23] described the measuring technique for the Q-angle by using the anterior superior iliac spine as the proximal landmark. They also adopted the goniometric method, with the subject in the supine position, with the knees extended and the quadriceps muscles relaxed.[23] Omololu, Ogunlade and Gopaldasani[27], Veeramani Raveendranath *et al.*[24] and Maharjan, Shrestha, Khanal, Chaudhary and Karn[28] measured the Q-angle in asymptomatic knees with the subject in the supine position, knees extended and the quadriceps muscles relaxed. Maharjan *et al.*[28] however slightly flexed the knees by 10 degrees.

The means for the Q-angle in asymptomatic knees were found to range between 10.6[27] to 13.94[28] degrees for males and 13.94[28] to 21[27] degrees for females. A Q-angle in excess of 20 degrees is thought to be associated with extensor mechanism dysfunction, although there is still little scientific evidence to support this.[21]

2.4 THE MORPHOLOGY OF THE PATELLAR TENDON

The patellar tendon is a flat structure, which derives primarily from the tendon of the rectus femoris muscle that extends over the anterior surface of the patella, to insert on the tibial tuberosity.[3] It runs in an oblique, lateral direction.[1] The patellar tendon also inserts on the distal margin of the patella. This attachment was found to never extend to the posterior surface of the patella.[29] As the patellar tendon extends over the patella, the tendon tapers towards its insertion on the tibial tuberosity.[29]

The patellar tendon also forms part of the extensor mechanism of the PFJ and with its laterally directed fibres to the tibial tuberosity, it contributes to the valgus alignment of the lower limb.[1]

The length of the patellar tendon is used to determine the height of the patella.[30] The height of the patella is regarded as an important factor in evaluating the PFJ for potential instability[31], as patella alta (high-riding patella) and patella baja (low-riding patella) have been associated with PFJ instability.[32–34] In patients with PFJ instability, it was found that the patellar tendon length is significantly longer and usually exceeds 50 mm in length.[35]

The length of the patellar tendon was reported to have a mean ranging from 40.20 mm[36] to 69.74 mm.[37] Olateju *et al.*[37] reported a mean length of 69.74 mm, from a morphometric analysis of South Africans with a European ancestry. They measured the length of the patellar tendon from the apex of the patella to the tibial tuberosity. Basso *et al*.[29] measured the length from the apex of the patella to the most distal attachment of the patellar tendon and found a similar mean length of 64.20 mm. Andrikoula *et al*.[3] did not specify the extent of the measurement but found a length of 43 mm whilst researching the extensor mechanism on cadavers, similar to the findings of Zooker, Pandarinath, Kraeutler, Ciccotti, Cohen and Deluca[38] (mean 42 mm) who measured the length from the distal apex of the patella to the proximal part of the tibial tuberosity. By means of magnetic resonance imaging (MRI), Yoo *et al.*[36] found a mean length of 40.20 mm from the apex of the patella to the proximal part of the tibial tuberosity. Similarly, Neyret *et al.*[35] found a mean length of 44 mm with MRI.

It is widely known that patella alta is associated with lateral deviations of the patella.[32–34] Reider, Marshall, Koslin, Ring and Girgis[39] described a negative correlation between the length of the patellar tendon and the width of the MPFL. They reasoned that this correlation may resemble the probability that patella alta presents with a less robust or even absent MPFL.

2.5 THE MORPHOLOGY OF THE PATELLA

The patella consist of an anterior surface, which is covered by the superficial fibres of the rectus femoris muscle[40], and a posterior surface of the patella which is in contact with the trochlea of the femur.[41] The posterior surface of the patella can further be divided into superior and inferior parts. The inferior part of the patella, the non-articulating part or the apex of the patella, serves as the attachment site for the deep fibres of the patellar tendon. The superior or articulating part of the patella consists anatomically of the medial and lateral facets of the patella.[41] The articulating part of the patella is dome shaped with a median ridge which separates the facets of the patella.[37,41]

The quadriceps muscle has a trilaminar structure and share a common tendon of insertion on the superior border of the patella.[3] Most of the superficial fibres of the rectus femoris muscle proceed anteriorly over the patella and form the superficial fibres of the patellar tendon.[40] For the deeper structures of the trilaminar structure of the quadriceps muscles, the vastus medialis and vastus lateralis muscles attach to the superior medial and superior lateral borders of the patella respectively[40] while the vastus intermedius attaches almost perpendicularly to the superior border of the patella.[3]

Wibeeg[42] was the first to classify the morphology of the patella based on the width of the medial and lateral facets of the patella, with consideration of the general shape. Following from this classification, the widths of the medial and lateral facets were compared. When the facets are of the same width, both having a concave shape it was named Type I; when the medial facet (flat and slightly convex) is smaller than the lateral facet it was named Type II and when the medial facet (convex) is considerably smaller than the lateral facet it was pronounced Type III.[42,43] Koyuncu, Cankara, Sulak, Özgüner and Albay[44] ignored the general shape and classified the patella as Type A to C. Widths of the facets that are equal were classified as Type A, when the width of the medial facet was smaller than the lateral it was regarded as Type B and when the width of the lateral facet is smaller than the medial, it was named Type C. They found that the most prevalent was Type B (50%) in foetuses, which is similar to Type II reported for adults. During an MRI study by dos Santos Netto, de Brito, Severino, Campos, Nico, de Oliveira and Severino[45], 52% and 48% of stable knees fitted into the model of Type II and Type I respectively. According to Higuchi, Arai, Takamiya, Miyamoto, Tokunaga and Kubo[46] similar results were found for healthy asymptomatic subjects. Olateju *et al.*[37] came to the same conclusion from cadaver studies. They were in agreement that Type II is the most prevalent.[37] Thus, the dimensions of the superior articulating surface is accepted as generally being Type II, with the medial facet smaller than that of the lateral facet.[37,39,44]

A smaller medial facet leads to an increase in the facet ratio [Lateral Facet/Medial Facet], and consequently more prevalence of Type II and Type III patella in trochlear dysplastic knees with patellofemoral instability.[43] It is speculated that the reason for this is an insufficient pull of the medial patellofemoral complex in the developing knee, leading to a smaller medial facet.[43]

Yoo *et al.*[36] concluded that although the measurements of the patella are significantly different for males and females, the range of the overlap (grey zone) is great.

2.6 THE MORPHOLOGY OF THE MEDIAL PATELLOFEMORAL LIGAMENT

Reference to the MPFL was already made as far back as 1880 when W.R. Williams[47] named the MPFL the "internal lateral ligament of the patella". He described the ligament as being fixed to the lower part of the medial border of the patella, and being blended with the insertion of the vastus intermedius and consisting of a slight band of nearly transverse fibres, which passes from the medial condyle of the femur immediately below the tubercle for the adductor magnus tendon to the medial border of the patella. Tenney[48] described the MPFL as a "flat, triangular band passing from the prominence on the internal femoral condyle to the upper half or two thirds of the inner border of the patella." He also confirmed the attachment to the vastus intermedius muscle tendon.

In 1981, Reider *et al.*[39] found the MPFL to be only present in 35% of the knees they dissected. They did not focus on the MPFL because it was not the main objective of their study. In later studies, however, the MPFL was found to be present in between 88% and 100% of the knees dissected.[16,49,50] This supports the latest view that the MPFL is present in the knees of the majority of human bodies.

The first detailed anatomical description of the MPFL was done by Feller *et al*.[17] in 1993. They described the MPFL as fan-shaped, with a small distal attachment on the medial side of the femur and a larger proximal attachment on the medial margin of the patella.[17] Occasionally the MPFL can also have an hourglass shape[5,50], or have the same width in the middle as the width it has at the femoral attachment.[51] The general anatomical morphometry of the MPFL was found by Feller *et al.*[17] to vary between individuals, but not between the knees of the same individual. However, Aragão, Reis, Vasconcelos, Feitosa and Nunes[52] found the morphometry of the MPFL to vary between the knees of the same individual.

In an anterior approach the MPFL is exposed in the second layer when the first layer of the medial side of the knee is removed.[15] It can sometimes be difficult to expose the MPFL because of the fusion and the intervention between the first and second layer.[53] This has led Mochizuki, Nimura, Tateishi, Yamaguchi, Muneta and Akita[54] to apply a different dissection technique in order to evaluate the MPFL. They approached the MPFL from the posterior side. This was achieved by reflecting the patella medially and by removing the third layer (the synovial capsule) to expose the

MPFL. This approach enabled them to clearly observe the MPFL and gauge the extent of the patellar attachment.

The attachment of the MPFL to the medial margin of the patella can vary greatly.[52] It can attach to the proximal third[52,55], the middle third[52], the proximal two thirds[16,53,55], the distal two thirds[52], the superior half[50,51,56], the inferior half[50] or the complete length of the medial border of the patella.[52,55]

The documented mean width of the MPFL's attachment to the patella ranged from 17 mm to 28.20mm.[16,55,56] Steensen *et al.*[56] found the mean width of the MPFL attachment to the medial border of the patella to be 17mm by using an anterior approach. They described the attachment predominantly to the superior half of the medial border of the patella. Baldwin[16], who also utilised an anterior approach, found the MPFL to be attached inseparably to the proximal two thirds of the patella and also to the vastus medialis oblique (VMO) muscle insertion to the patella. This attachment was found to be 28.20mm in width.[16]

The MPFL is found deep to the VMO muscle and is not tightly adhered to the epimysium of the muscle. As the VMO muscle becomes more tendinous, the attachment to the MPFL becomes inseparable and they collectively attach to the superomedial border of the patella.[4,16,17] Feller *et al.*[17] therefore postulated a possible 'dynamic role' of the VMO muscle on the stability of the PFJ. Nomura *et al.*[53] further elaborated on this hypothesis and suggested that the VMO is a direct and indirect stabiliser of the patella, indirectly pulling the patella medially via the MPFL. In a biomechanical study that specifically focused on the dynamic role of the VMO muscle on the MPFL, the importance of the attachment was emphasised.[4] Panagiotopoulos *et al.*[4] explained that this mechanism that consists of meshed fibres of the VMO, pulls and guides the patella with the MPFL into the femoral groove during initial flexion.

Conlan *et al.*[6] mentioned "proximal" and "distal" fibres, regarding the patellar attachment. They found that the proximal fibres insert on the posterior surface of the VMO muscle and aponeurotic fibres of the vastus intermedius. The distal fibres of the MPFL were described as inserting on the proximal half of the patella. Mochizuki *et al.*[54] found the proximal fibres were mainly attached to the vastus intermedius tendon, without tight adhesion to the VMO. They described the distal fibres as integrated with the deep layer of the medial retinaculum and attached to the patellar tendon. Kang, Wang, Chen, Su, Zhang and Yan[57] later described the fibres, both proximal and distal, as functional bundles. They found the MPFL to have a "superior oblique fibre bundle" and an "inferior straight fibre bundle". The superior oblique bundle was described as attaching to the superior part of the patella and the suprapatellar quadriceps fibres, and the inferior straight bundle attaches to the superiomedial aspect of the patella. These fibre bundles are not completely separate. In a study by Viste *et al.*[51] they were unable to find the functional bundle organisation.

The attachment of the MPFL to the aponeurotic fibres of the vastus intermedius muscle was not mentioned in all the literature reviewed[4,39,56–58]; only a minority of researchers found this attachment present in all the knees dissected.[6,48,54] Mochizuki *et al.*[54] found the mean width of the attachment to be 24.30mm on the medial margin of the aponeurotic fibres of the vastus intermedius muscle. Kikuchi, Tajima, Yan, Kamei, Maruyama, Sugawara, Fujino, Takeda and Doita[59] found this attachment to have a mean width of 28.50mm and concluded that this attachment is significantly longer than the insertion of the MPFL to the patella.

The length of the MPFL can be determined by MRI scans[45,46,60] or anatomical dissections.[51,54,55] In cadaver dissections using an anterior approach, Kang *et al.*[57] measured the length of the MPFL transversely (femoral attachment to patellar attachment in a straight line) and obliquely (femoral attachment to the most superior attachment of the MPFL) and found the length to be 71.78mm and 73.67mm respectively. This is similar to Placella *et al.*[55] who used the posterior approach to expose the ligament, but measured the MPFL from the anterior surface and found the transverse length to be 72mm. On the other hand, Mochizuki *et al.*[54] used the posterior approach to expose and measure the MPFL. They found the transverse and oblique length to be 56.30mm and 70.70mm respectively.[54] The transverse length of the MPFL was measured from its attachment to the femoral condyle to its attachment on the medial border of the patella and it ranged from 47.37mm to 72mm.[4,51,55] The minimum length of the MPFL ranged from 45mm to 63.50mm[49,57], whilst the maximum length of the MPFL ranged from 50mm to 81.50mm.[4,57]

The mean length of the MPFL determined by MRI scans ranged from 43mm to 49.04mm and had a minimum and maximum range of 36.10mm to 38.80mm and 57.90mm to 61.80mm respectively.[45,46,60]

The width in the middle of the MPFL was measured at a point halfway from the femoral attachment to the patellar attachment.[51,52,55] The mean width in the middle of the MPFL was found to range from 10.50mm to 20.20mm.[51–53,55] The minimum and maximum ranges for the middle width of the MPFL were 6mm to 14mm and 16mm to 27.50mm respectively.[51,52] The anterior approach was used in all the reported cases. Aragão *et al.*[52] stated that the middle of the MPFL was only measured if the lower margin of the MPFL was well defined and this was possible in 80% of the cases. This is similar to the findings by Tuxøe *et al.*[49], who stated that in 23% of the knees they studied, the free distal edge of the MPFL was not well defined.

The mean femoral attachment width of the MPFL ranged from 8.80mm to 19mm.[49,51,55] Tuxøe *et al.*[49] measured the femoral attachment width 10mm anterior to the centre of the adductor tubercle and found the mean length of the femoral attachment to be 19mm. Steensen *et al.*[56] measured the width at the attachment to the medial epicondyle and found the mean width to be 15.40mm; this was similar to the findings of Panagiotopoulos *et al.*[4] who found the width at the femoral insertion to be 14.87mm. Viste *et al.*[51] reported the mean length and range of the femoral attachment width to be 8.80mm and 5mm to 14mm respectively. Their finding is similar to that of Placella *et al.*[55] who found the mean width of the femoral attachment to be 8.90mm.

2.7 THE GEOMETRY OF THE FEMORAL TROCHLEAR GROOVE

The inferior surface of the patella glides over the trochlear groove of the femur during flexion and extension of the knee. Both the depth and the altitude of the articular facets of the FTG contribute towards the stability of the patella.[2] As the knee flexes, the resultant force of the patellar tendon and the quadriceps musculature tension combine to produce a posterior force vector on the patella.[2] In full extension. however, the posterior force vector has only a small posterior component.[2] The normal patella bears 60% of the joint load on the lateral facet, and this is reflected by the larger lateral than medial facet of the patella.[2] In full extension, the patella disengages with the trochlea of the femur and is solely dependent on soft tissue structures for its stability.[11] Only during the early phase of flexion does, the distal lateral edge of the patella come into contact with the FTG. In early flexion the patella presses against the proximal lateral extremity of the trochlea, which extends further proximally on the lateral side compared to the medial side.[2] From the description above it is clear that the patella is guided medially into the FTG.[2] The MPFL acts as a check rein to direct the patella medially into the FTG before engament.[13] Therefore, the patella has an initial medial shift, as it engages with the trochlea, followed by a progressive lateral shift as it follows the orientation of the femoral trochlear groove.[2]

A shallow trochlear groove will allow the patella to be displaced laterally more easily, and this has been proven *in vitro*.[61] Patellar lateralisation was significantly different in trochlear dysplastic knees compared to the control group.[62] Subjects with trochlear dysplasia are therefore prone to lateral deviation of the patella.[34,63,64] A shallow trochlea of the femur would produce a larger trochlear angle and it was found that the severity of extensor mechanism dysplasia correlated with an increase in this angle.[34] Farahmand *et al.*[40] quantitatively studied the geometry of the FTG in cadavers, and concluded that the FTG appeared to be constant along its length. This includes the trochlear angle and the trochlear depth.

Several measurements are required to determine the geometry of the femoral trochlear groove. The geometry of the FTG can be determined by means of MRI scans[45,62,64,65] or by means of photometric analysis.[66–68] The trochlear groove geometry include the trochlear groove depth, the trochlear angle and the trochlear facet asymmetry (the width ratio of the medial and lateral facets of the trochlear groove). Trochlear groove geometry plays an important role in the stability of the PFJ.[62,65,69] The mean trochlear angle was found to range between 143.05 to 148.48 degrees[45,64,65] when MRI scans were used and 146.1 to 148.8 degrees[66–68] with photometric analysis. The mean trochlear depth ranged from 4.20mm to 6.40 mm[45,62,64,65] when MRI scans were used and was found to be 4.50mm[66] with photometric analysis. The mean MRI ratio of the medial and lateral facets of the trochlear groove ranged from 0.57 to 0.66[62,64,65] and with photometric analysis the ratio was found to be 0.49.[66] Measurement of the FTG in patients with trochlear dysplasia, found the trochlear depth to be less than 3mm[62,65,69], and the trochlear groove angle to be more than 150 degrees.[65,69,70] Trochlear facet asymmetry of less than 0.40 is indicative of trochlear dysplasia.[62,65,69]

Chapter 3

MATERIALS AND METHODS

3.1 GENERAL DEMOGRAPHICS AND STUDY POPULATION

Twenty-seven adult formalin-fixed cadavers were investigated. Only cadavers with no visible pathology or injuries to the knee were included. Ten of these cadavers had to be excluded from the study, due to previous knee surgery, the presence of pathology or damage to the medial patellofemoral ligament (MPFL). The seventeen cadavers included in the study consisted of 10 male and 7 female adult cadavers with a mean age of 61 years (age range 31 to 87 years). Both knees were used, except for one male cadaver where only the left knee was included because the MPFL was not present in the contralateral side.

3.2 MEASUREMENT OF THE QUADRICEPS ANGLE (Q-ANGLE)

The cadavers were placed in a supine position, with the knees extended. An anterior midline skin incision was made from 20 centimetres proximal to 20 centimetres distal to the patella. From both ends of this midline incision, transverse incisions were made over the quadriceps muscle and the anterior tibia, respectively. The skin flaps were removed from the underlying superficial facia by reflecting them from the midline incision. Superficial fascia covering the anterior surface of the patella and patellar tendon were removed to expose the patella and patellar tendon. Both knees were dissected in the same manner.

Both feet were placed perpendicular to the floor, with the knees fully extended and the quadriceps femoris muscles relaxed. The feet were then stabilised with the medial malleoli 12cm apart. This was accomplished by placing a wooden block (11cm (height) x 12cm (width) x 14.5cm (length)) (Figure 3.1) between the feet.[71]

A wooden board (30cm x 14.5cm) was attached to the inferior surface of the block to ensure that both feet were perpendicular to the floor (Figure 3.1). The feet were tightly bound to the board by means of string.

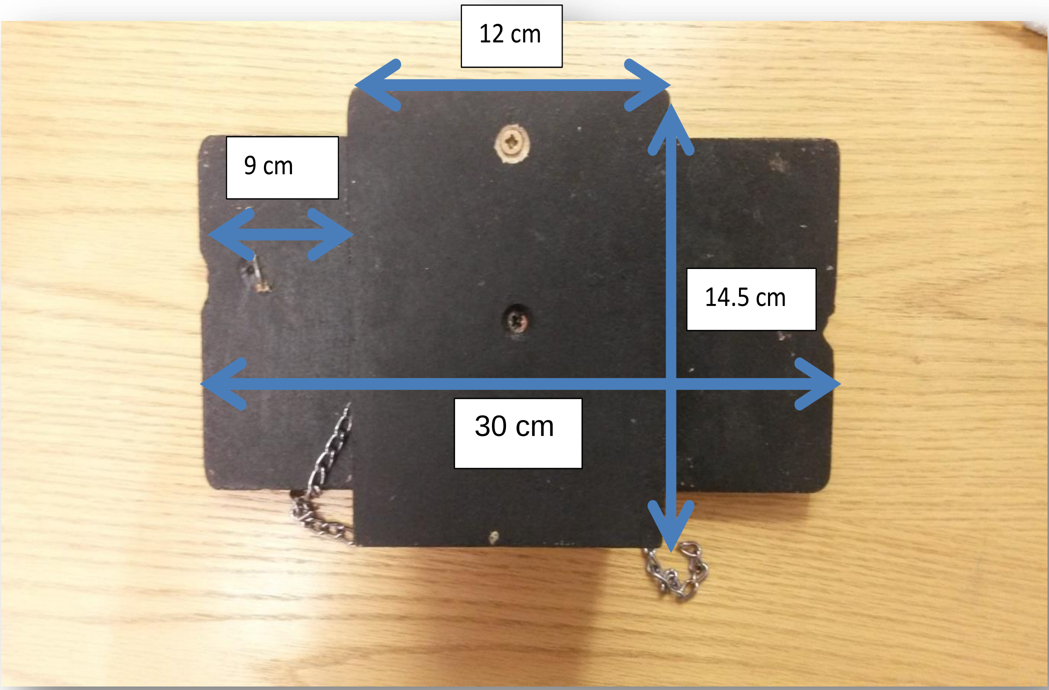

Figure 3.1: The block that was used in this study

The Q-angle involves three bony landmarks: the centre of the patella (CP); the centre of the tibial tuberosity (TT) and the anterior superior iliac spine (ASIS).[24]

The CP was determined by the intersection of two lines. One line was drawn through the widest part of the patella and the second line was drawn through the highest part of the patella. The centre of the TT was defined as the point of greatest prominence and was determined by palpation. The ASIS was exposed by clearing skin and superficial fascia from it. The ASIS, the CP and the TT were all connected by means of a string.

The centre of a long arm goniometer was placed on the centre of the patella and the arms in line with the ASIS and the centre of the TT. The Q-angle is the angle formed between the extended lines drawn from the TT to CP and the ASIS to the CP. The Q-angle was then visually recorded with the goniometer (Figure 3.2).

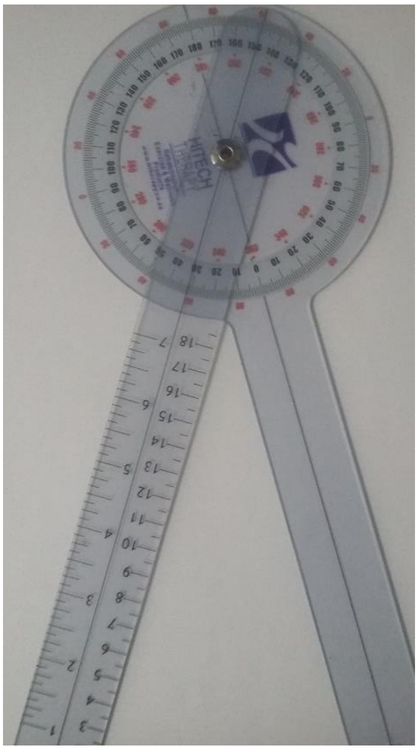

Figure 3.2: The goniometer that was used in this study

3.3 EXPOSURE AND MEASUREMENT OF THE PATELLAR TENDON

The patellar tendon was exposed by reflecting the skin and overlying soft tissues (cf. paragraph 3.2). A straightened patellar tendon was ensured by placing the knee in a flexed position not exceeding 45 degrees.[44] The patellar tendon was then measured with a digital sliding Vernier calliper, accuracy 0.01mm (Figure 3.3).

Figure 3.3: The digital sliding Vernier calliper that was used in this study

A needle was placed as a marker at the apex of the patella, indicated by the green marker in Figure 3.4. The proximal (PPTW) and distal (DPTW) widths of the patellar tendon were measured from the medial to lateral borders. The PPTW was measured at the apex of the patella, indicated by the green marker, and the DPTW was measured at the proximal border of the patellar tendon attachment to the TT (Figure 3.4).[36] The length of the patellar tendon (PTL) was measured at the apex of the patella, indicated by the green marker, as the linear distance between the marker and the proximal border of the tibial tuberosity.[36–38]

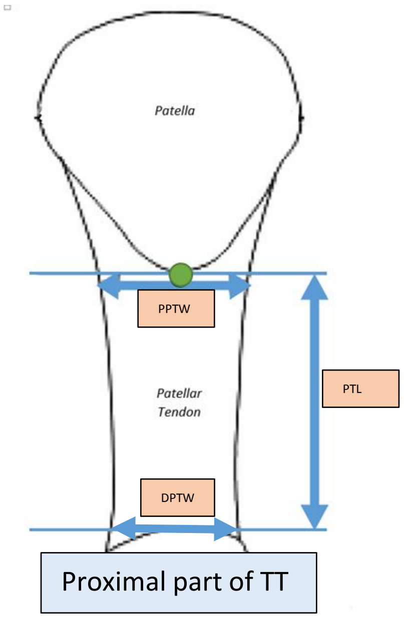

Figure 3.4: Measurements of the patellar tendon. PPTW (Proximal Patellar Tendon Width), PTL (Patellar Tendon Length), DPTW (Distal Patellar Tendon Width), TT (Tibial Tuberosity). Image adapted from Koyuncu *et al.*[44]

3.4 EXPOSURE AND MEASUREMENT OF THE PATELLA

The vastus lateralis muscle was isolated and a lateral incision was made through the muscle, as well as a lateral incision at the parapatellar side through the lateral retinaculum.[55] Another incision was made 10cm proximally to the patella through the quadriceps femoris muscles and the patellar tendon was detached from the tibial tuberosity. On the lateral side of the patella, the synovial capsule was transsected and the patella reflected medially. A digital sliding Vernier calliper was used to do all the measurements on the posterior surface of the patella (Figure 3.3).

A needle was placed as a marker on the highest point of the median ridge between the lateral and medial facets of the patella, green marker (Figure 3.5). For measurement consistency the medial and lateral facets were measured from this marker. The medial facet (MFWP) and lateral facet widths (LFWP) were measured from the greatest parts of the respective medial and lateral borders of the patella to the marker on the median ridge.[37,41] The height of the articulating surface (ASHP) was measured between the most superior and inferior margins of the articulating surface of the patella.[41] The osseous length of the patella (OLP) was measured between the superior border and its inferior apex.[37] Finally, the width of the osseous patella (OWP) was measured between the widest points of its medial and lateral borders in a linear line (Figure 3.5).[37,41]

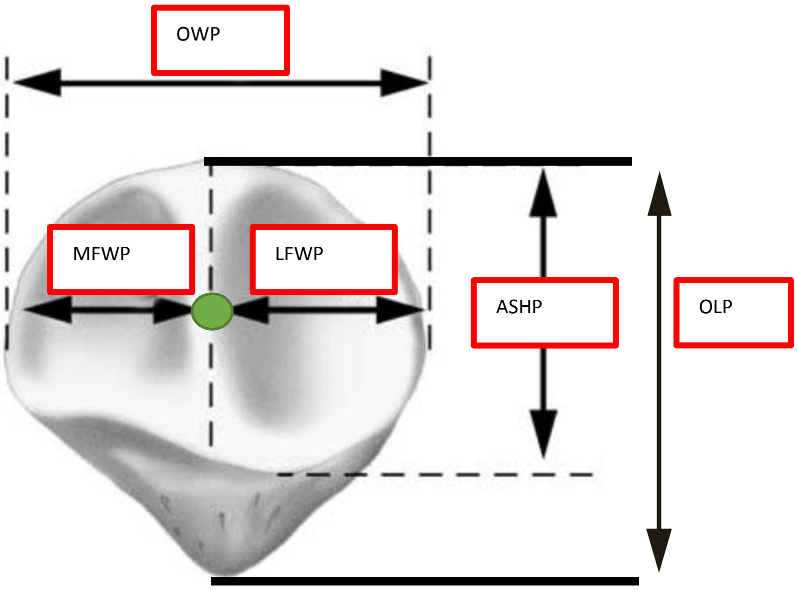

Figure 3.5: The different measurements of the patella. Medial facet width (MFWP). Lateral facet width (LFWP). Height of articulating surface (ASHP). Osseous width of patella (OWP). Osseous length of the patella (OLP). This image was adapted from Baldwin and House.[41]

3.5 EXPOSURE AND MEASUREMENT OF THE MEDIAL PATELLOFEMORAL LIGAMENT

The medial side of the knee consists of three layers, as defined by Wanner and Marshall.[15] Layer one consists of deep fascia; layer two of several ligaments and the MPFL; and layer three of the capsule of the knee joint.[15]

The skin and superficial fascia were already removed in the previous dissection and the patella reflected medially (cf. paragraph 3.2 and paragraph 3.4). Layer 1 was removed from the medial side of the knee by sharp dissection which was continued until the superior border of the MPFL was visible. The superficial anterior capsular branch of the descending genicular artery was now identified (Figure 3.6). It is documented that as long as the descending genicular artery is preserved, the MPFL is regarded as undamaged.[16]

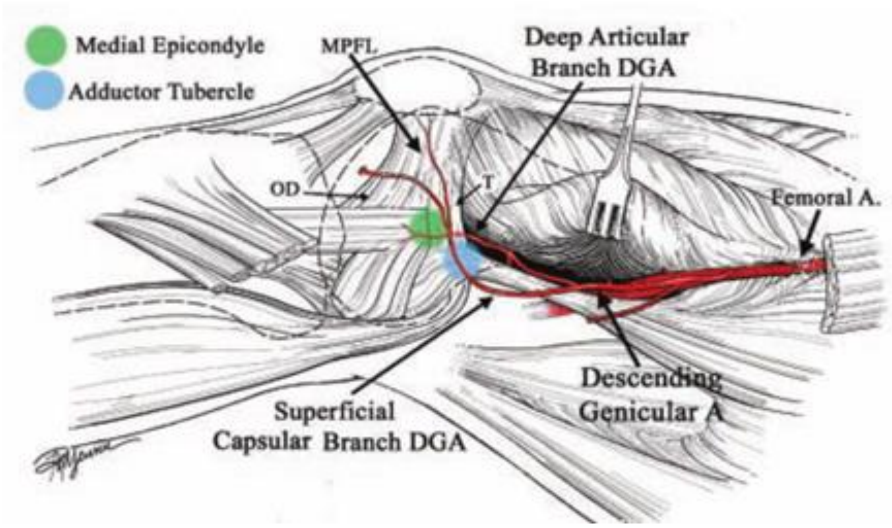

Figure 3.6: The branching pattern of the descending genicular artery (DGA). This image was adapted from Baldwin.[16]

Removal of the synovial capsule now continued from its femoral insertions on the lateral and medial femoral condyles and also from its superior insertion on the base of the patella. Layer three was now completely removed, exposing the posterior surface of the second layer.

The patella was now gently pulled medially to expose the white collagen fibres of the MPFL. By way of palpation and visualisation, the fibres of the MPFL were isolated and measured from their posterior surface (Figure 3.7).

All measurements of the MPFL were taken from its posterior aspect with a digital sliding Vernier calliper (Figure 3.3). The femoral attachment of the MPFL was determined by inserting a blunt dissector under the MPFL and following it distally until it was arrested by the bony attachment. The patellar and femoral attachments were marked as illustrated in Figure 3.7: superior (1); middle (2) and inferior (3) on the medial side of the patella and inferior (4); middle (5) and superior (6) on the medial femoral condyle. Finally, the greatest part of the superior ridge of the patella was also marked (7). All of these attachment points were marked with needles. During the measurement process, manual tension was placed on the MPFL by gently pulling the patella to ensure the MPFL was as straight as possible.

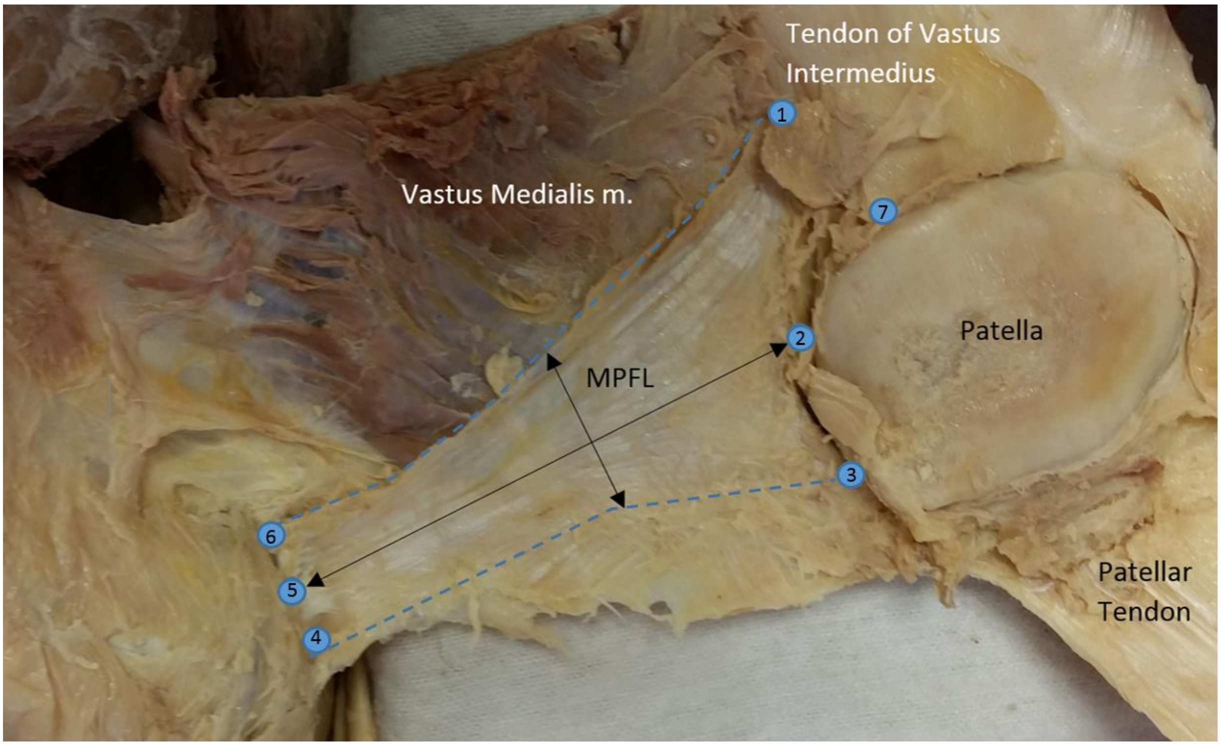

Figure 3.7: Attachments of the MPFL with the patella reflected medially. 1. Superior point of proximal attachment. 2. Middle point of proximal attachment 3. Inferior point of proximal attachment. 4. Inferior point of femoral attachment 5. Middle point of femoral attachment 6. Superior point of femoral attachment. 7. The superior ridge of the patella.

The width of the proximal (MPFLP) and femoral attachment (MPFLF) sites of the MPFL were measured from 1-3 and 4-6 respectively (Figure 3.7). The length of the MPFL (MPFLL) was measured between the middle proximal attachment point (2) and the middle femoral attachment point (5) (Figure 3.7). The width of the MPFL was also measured halfway between points 2 and 5 (MPFLM). Finally, the width of the attachment of the MPFL to the vastus intermedius tendon (MPFLVI) was measured along the border of the tendon between the superior ridge of the patella (7), and the superior proximal attachment of the MPFL (1) (Figure 3.7).[54]

3.6 THE GEOMETRY OF THE FEMORAL TROCHLEAR GROOVE

All the geometrical measurements of the femoral trochlear groove were obtained by using the *ImageJ* software programme.[72] The geometry of the femoral groove consists of the depth of the trochlear groove, the trochlear facet asymmetry and the trochlear angle. The trochlear depth and facet asymmetry were calculated from the photometric measurements. Trochlear depth can be calculated according to the formula (AMM + ALM)/2 – ADP[64] and the asymmetry of the trochlear facets was determined by the ratio of the medial to lateral facet groove widths of the FTG (MFGW/LFGW).[64]

In order to prepare the femoral trochlear groove, both the knee and the hip joints were disarticulated. All of the soft tissue structures on the femur were removed. The distal end of the femur was placed on a hard board to ensure that both the medial and lateral condyle rested on a horizontal plane.[66] The medial and lateral condyles were perpendicularly aligned with the hard board (Figure 3.8).[68]

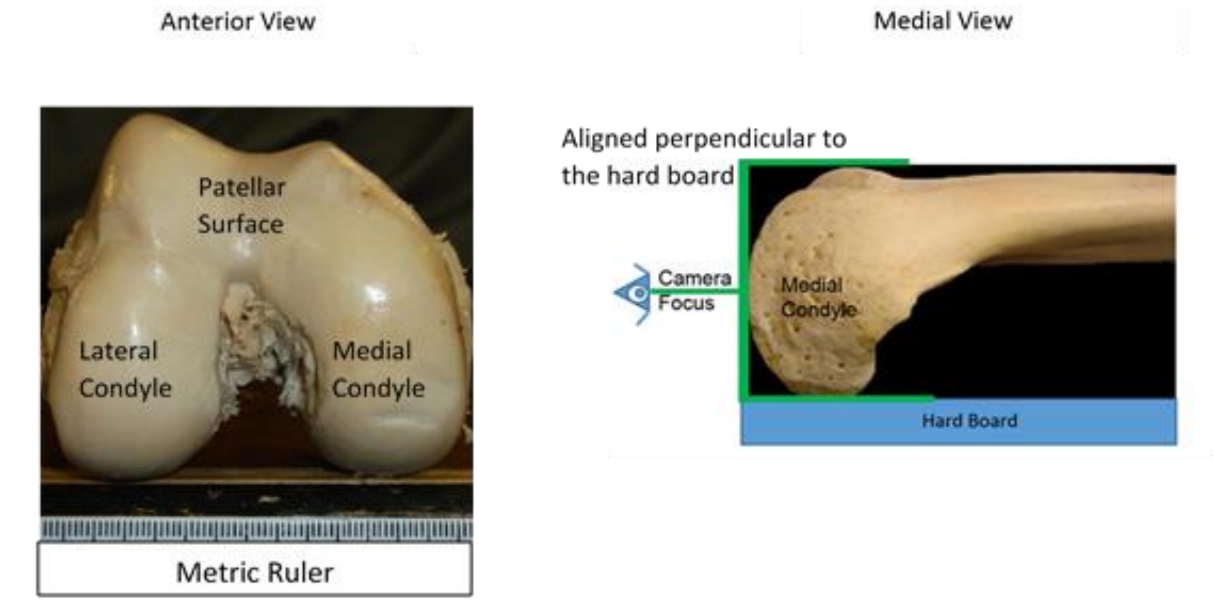

Figure 3.8: Alignment of the distal end of the femur on the hard board

A metric ruler was placed on the distal end of the hard board (Figure 3.9). The most prominent parts of the lateral and medial condyles of the femur were perpendicularly aligned with a metric ruler. The distal end of the femur was centred in the screen of the camera.[68] Identification detail of each distal femur was placed next to the femur to appear on the photographs, e.g. “Left Knee, Cadaver B201236”.

Morphological measurements of the femoral trochlear groove included the maximum altitude of the medial (AMM) and lateral (ALM) margins of the medial and lateral condyles of the femur respectively, the maximum altitude of the deepest point of the femoral trochlear groove (ADP), the groove width of the lateral and medial trochlear facets (MFGW & LFGW) and the trochlear angle (α) (Figure 3.9).

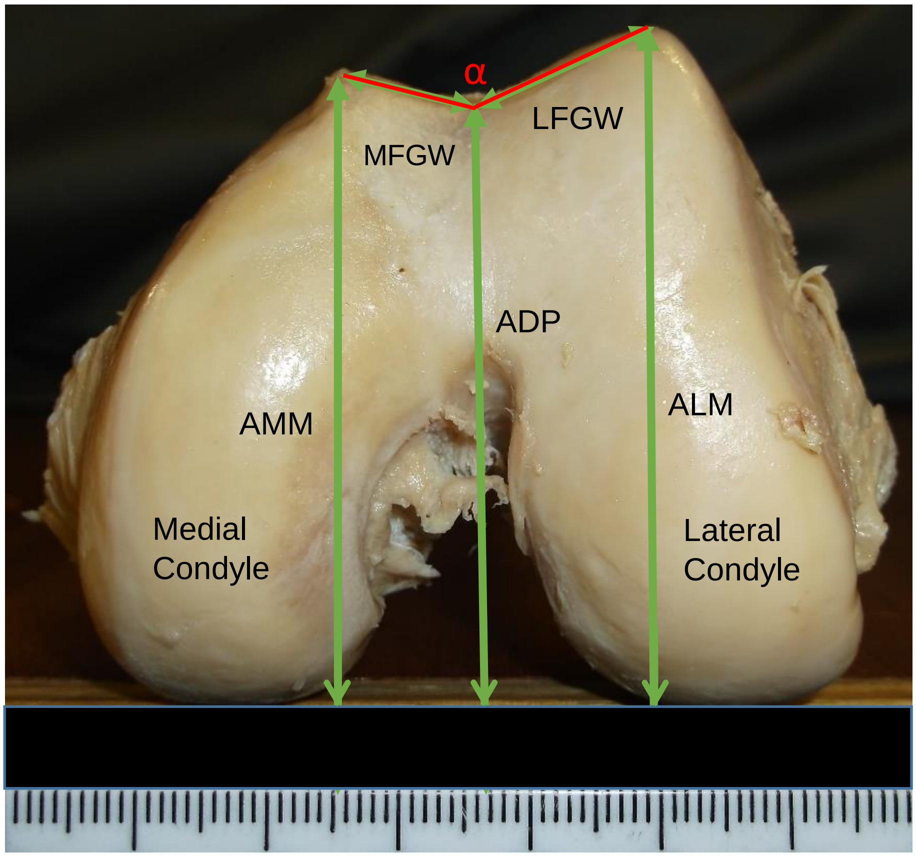

Figure 3.9: The different measurements of the distal end of the femur. The medial facet groove width of the FTG (MFGW). The lateral facet groove width of the FTG (LFGW). The altitude of the medial margin of the medial condyle of the femur (AMM). The altitude of the lateral margin of the lateral condyle of the femur (ALM). The altitude of the deepest point of the FTG (ADP). The trochlear angle (α).

The width of MFGW and LFGW were measured from the deepest point on the femoral groove to the most prominent margin of the respective condyle.[68] The altitude of AMM and ALM were measured from the posterior condyle tangent line to the margins of the respective condyles.[68] The altitude of the deepest point of the femoral trochlear groove (ADP) extends from the deepest point of the trochlear groove to the posterior condyle tangent line.[68] The trochlear angle (α) of the femur is the angle formed by an extension of the line from the deepest point of the trochlear groove and the most prominent margin of the medial and lateral femoral condyles respectively.[68]

3.7 INTRA- AND INTER OBSERVER ACCURACY

Intraobserver accuracy was ensured by taking all measurements three times using the average of the three measurements. All measurements were also measured by the co-study leader to ensure interobserver accuracy.

3.8 STATISTICAL ANALYSIS

3.8.1 Descriptive statistics

The descriptive statistics of the study population were analysed using the SAS/STAT software®[1]. The variables were tabulated and simple statistics for each of the parameters included were calculated from the data (Appendix B). This included the mean; the standard deviation; as well as minimum and maximum deviation.

3.8.2 Primary analysis

Spearman's rank correlation coefficient was used in this study to determine if two variables have a monotonic relationship. This method is non-parametric, and is used when data do not meet the assumptions of normality.[73] The data were not normally distributed.

®[1] SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc. in the USA and other countries. ® Indicates USA registration.

Chapter 4

RESULTS

The results of 33 knees from 17 adult embalmed cadavers met the inclusion criteria and were included for further research. The statistical analysis included descriptive statistics and Spearman's rank correlation coefficient.

Spearman's ranked correlation coefficient (r_s) is a value ranging from +1 to -1. A perfect positive monotonic correlation coefficient between two variables will have a value of +1 and a perfect negative monotonic correlation coefficient is indicated by -1. If no monotonic correlation coefficient exists between two variables the correlation coefficient will be 0. The critical Spearman's rank correlation coefficient for a sample size of 33 was determined to be 0.482 (Appendix C).[74] A correlation coefficient value of 0.482 and more between the variables of the MPFL and the other parameters measured in this study were considered relevant and accordingly applied.

4.1 THE QUADRICEPS ANGLE (Q-ANGLE)

The Q-angle was determined by connecting the tibial tuberosity (TT), the centre of the patella (CP) and the anterior superior iliac spine (ASIS) with a string and then by measuring the angle that was formed at the CP with a goniometer.

The Q-angle ranged from 1.5 to 16.50 degrees, with a mean value of 10.57 degrees (Table 4.1). Nineteen knees had a Q-angle value greater than the mean. As indicated by the r_s-values in Table 4.2, none of the five variables of the MPFL evaluated demonstrated any correlations with the Q-angle.

Table 4.1: Descriptive statistics of the quadriceps angle (Q-angle)

Measurement	Mean degrees	Standard Deviation	Minimum degrees	Maximum degrees
Q-angle	10.57	3.62	1.50	16.50

Table 4.2: The correlation coefficients of the five measurement variables of the MPFL with the Q-angle

Variables	MPFLL	MPFLP	MPFLF	MPFLM	MPFLVI
Q-angle	-0.017	0.071	0.112	0.201	-0.418

* Spearman's ranked correlation coefficient **≥ 0.482**

4.2 THE PATELLAR TENDON (PT)

The proximal patellar tendon width (PPTW) was measured at the level of the apex of the patella and was found to have a value ranging from 24.39mm to 36.49mm, with a mean value of 30.24mm (Table 4.3). Eighteen knees had a PPTW value of less than the mean. The PPTW was found to have a positive correlation coefficient with both the length of the MPFL (MPFLL) (r_s= 0.492) and the width of the femoral attachment of the MPFL (MPFLF) (r_s= 0.489) (Table 4.4).

The distal patellar tendon width (DPTW) was measured at the proximal border of the attachment of the patellar tendon to the TT and was found to have a value ranging from 19.94mm to 29.38mm, with a mean value of 24.37mm (Table 4.3). Seventeen knees had a lesser value than the mean. The DPTW was found to have a positive correlation coefficient with the MPFLF (r_s= 0.548) (Table 4.4).

The patellar tendon length (PTL) was measured from the apex of the patella to the most proximal part of the tibial tuberosity and the length was found to range from 34.94mm to 52.97mm, with a mean value of 45.84mm (Table 4.3). Nineteen knees had a PTL value greater than the mean. The PTL was found to have a positive correlation coefficient with both the MPFLL (r_s= 0.497) and the width of the attachment to the vastus intermedius tendon (MPFLVI) (r_s= 0.487) (Table 4.4).

Table 4.3: Descriptive statistics of the patellar tendon

Measurement	Mean	Standard Deviation	Minimum	Maximum
The width at the proximal part of the patellar tendon **(PPTW)**	30.24	3.09	24.39	36.49
The width at the distal part of the patellar tendon **(DPTW)**	24.37	2.57	19.94	29.38
The length of the patellar tendon **(PTL)**	45.84	5.19	34.94	52.97

Table 4.4: The correlation coefficients of the five measurement variables of the MPFL with the patellar tendon

Variables	MPFLL	MPFLP	MPFLF	MPFLM	MPFLVI
PPTW	**0.492***	0.008	**0.489***	0.060	-0.200
DPTW	0.353	0.240	**0.548***	0.197	-0.090
PTL	**0.497***	0.015	0.176	-0.004	**0.487***

* Spearman's ranked correlation coefficient **≥ 0.482**

4.3 THE PATELLA

The medial facet width of the patella (MFWP) was measured from the medial border of the patella to the median ridge of the patella, and ranged from 19.07mm to 30.27mm, with a mean value of 23.45mm (Table 4.5). Seventeen knees were found to have a value greater than the mean. The MFWP was found to have a positive correlation coefficient with the MPFLL (r_s= 0.572) (Table 4.6).

The lateral facet width of the patella (LFWP) was measured from the lateral border of the patella to the median ridge of the patella, and ranged from 21.95mm to 31.19mm with a mean value of 26.93mm (Table 4.5). Nineteen knees had a LFWP value greater than the mean. No correlation coefficient was found between the LFWP and any of the MPFL parameters.

The articulating surface height of the patella (ASHP) was measured from the superior to the inferior border of the articulating surface of the patella. The height ranged between 28.66mm and 39.44mm, with a mean value of 33.23mm (Table 4.5). Seventeen knees had a lesser value than the mean. The ASHP was found to have a strong positive correlation coefficient with the MPFLL (r_s= 0.709) (Table 4.6).

The osseous width of the patella (OWP) was measured from the lateral to medial osseous border of the patella. The OWP was found to range between 38.11mm and 52.95mm, with a mean value of 44.55mm (Table 4.5). Eighteen knees had a value greater than the mean. The OWP was found to have a positive correlation coefficient with the MPFLF (r_s= 0.488) (Table 4.6).

The osseous length of the patella (OLP) was measured from the superior border to the inferior apex of the patella and ranged from 36.27mm to 51.66mm, with a mean value of 42.93mm (Table 4.5). Seventeen knees had a lesser value than the mean. The OLP was found to have a positive correlation coefficient with both the MPFLL (r_s= 0.590) and the MPFLF (r_s= 0.587) (Table 4.6).

Table 4.5: Descriptive statistics of the patella

Measurements	Mean	Standard Deviation	Minimum	Maximum
The medial facet width **(MFWP)**	23.45	2.79	19.07	30.27
The lateral facet width **(LFWP)**	26.93	2.60	21.95	31.19
Height of the articulating surface **(ASHP)**	33.23	2.72	28.66	39.44
The osseous width of the patella **(OWP)**	44.55	4.06	38.11	52.95
The osseous length of the patella **(OLP)**	42.93	4.08	36.27	51.66

Table 4.6: The correlation coefficients of the five measurement variables of the MPFL with the patella

Variables	MPFLL	MPFLP	MPFLF	MPFLM	MPFLVI
MFWP	**0.572***	0.196	0.147	0.155	-0.304
LFWP	0.391	0.025	0.350	0.193	-0.198
ASHP	**0.709***	0.069	0.366	0.217	0.176
OWP	0.461	0.101	**0.488***	0.186	-0.165
OLP	**0.590***	0.064	**0.587***	0.234	-0.172

* Spearman's ranked correlation coefficient **≥ 0.482**

4.4 THE MEDIAL PATELLOFEMORAL LIGAMENT (MPFL)

The MPFL length (MPFLL) was measured from the middle of the femoral attachment to the middle of the proximal attachment. The MPFL length (MPFLL) ranged between 54.27mm and 77.07mm, with a mean value of 67.53mm (Table 4.7). Seventeen knees had a MPFLL value greater than the mean.

The width of the proximal attachment of the MPFL (MPFLP) was measured from the superior to inferior border of the proximal attachment of the MPFL (c.f. Fig 3.7). The MPFLP ranged between 41.18mm and 66.50mm, with a mean value of 49.82mm (Table 4.7). Seventeen knees had a MPFLP value greater than the mean.

The width of the femoral attachment of the MPFL (MPFLF) was measured from the superior to inferior border of the femoral attachment of the MPFL and ranged from 7.59mm to 25.26mm, with a mean value of 14.70mm (Table 4.7). Eighteen knees had a MPFLF value lower than the mean.

The middle width of the MPFL (MPFLM) was measured in the middle of the MPFL by dividing the length of the MPFL in half and ranged between 13.52mm and 34.96mm, with a mean value of 24.02mm (Table 4.7). Eighteen knees had a value lower than the mean.

The length of the MPFL attachment to the vastus intermedius tendon (MPFLVI) was measured from the superior border of the proximal attachment of the MPFL to the superior border of the patella and ranged between 18.02mm and 35.42mm, with a mean value of 25.65mm (Table 4.7). Nineteen knees had a value lower than the mean.

Table 4.7: Descriptive statistics of the medial patellofemoral ligament

Measurements	Mean	Standard Deviation	Minimum	Maximum
The length of the MPFL **(MPFLL)**	67.53	5.68	54.27	77.03
The width of the patellar attachment **(MPFLP)**	49.82	4.76	41.18	66.50
The width of the femoral attachment **(MPFLF)**	14.70	3.62	7.59	25.26
The middle width of the MPFL **(MPFLM)**	24.02	4.43	13.52	34.96
The length of the MPFL attachment to the vastus intermedius tendon. **(MPFLVI)**	25.65	3.77	18.02	35.42

4.5 THE FEMORAL TROCHLEAR GROOVE (FTG)

All the measurements of the geometry of the femoral trochlear groove were done photometrically.

The medial facet groove width of the FTG (MFGW) was measured from the deepest point of the femoral trochlear groove (FTG) to the most prominent margin of the medial condyle. The width ranged between 8.47mm and 15.09mm, with a mean value of 12.04mm (Table 4.8). Twenty knees had a value greater than the mean. The MFGW was found to have a positive correlation coefficient with the MPFLL (r_s= 0.664) (Table 4.9).

The lateral facet groove width of the FTG (LFGW) was measured from the deepest point of the FTG to the most prominent margin of the lateral condyle. LFGW ranged from 12.76mm to 23.57mm, with a mean value of 18.42mm (Table 4.8). Eighteen knees had a LFGW lower than the mean. The LFGW had a positive correlation coefficient with both the MPFLL (r_s= 0.524) and the MPFLF (r_s= 0.485) (Table 4.9).

The altitude of the medial margin of the medial condyle of the femur (AMM) was measured from the most prominent margin of the medial condyle to the posterior condyle tangent line and ranged between 50.29mm and 67.88mm, with a mean value of 60.15mm (Table 4.8). Eighteen knees had a value greater than the mean.

The AMM was found to have a positive correlation coefficient with both the MPFLL (r_s= 0.566) and the MPFLF (r_s= 0.556) (Table 4.9).

The altitude of the lateral margin of the lateral condyle of the femur (ALM) was measured from the most prominent margin of the lateral condyle to the posterior condyle tangent line and ranged between 52.26mm and 71.25mm, with a mean value of 62.42mm (Table 4.8). Seventeen knees had a value greater than the mean. The ALM had a positive correlation coefficient with both the MPFLL (r_s= 0.619) and the MPFLF (r_s= 0.511) (Table 4.9).

The altitude of the deepest point of the FTG (ADP) was measured from the deepest point of the FTG to the posterior condyle tangent line and ranged from 48.74mm to 65.08mm with a mean value of 56.86mm (Table 4.8). Seventeen knees had a value greater than the mean. The ADP was found to have a positive correlation coefficient with both the MPFLL (r_s= 0.533) and the MPFLF (r_s= 0.577) (Table 4.9).

The trochlear angle (α) was determined from the extension of a line from deepest point of the groove to the most prominent margin of the lateral and medial femoral condyles and ranged from 134.85 to 158.58 degrees, with a mean value of 146.64 degrees (Table 4.8). Seventeen knees had a value greater than the mean. None of the five variables of the MPFL evaluated demonstrated any correlation coefficient with the trochlear angle (Table 4.9).

The depth of the FTG (DFTG) was determined mathematically ((AMM+ALM)/2-ADP)[63], and was found to range between 2.06mm and 6.46mm, with a mean value of 4.43 mm (Table 4.8). Eighteen knees had a value greater than that of the mean. The DFTG was found to have a positive correlation coefficient with the MPFLL (r_s= 0.601) (Table 4.9).

The trochlear groove asymmetry (TGA) was determined by dividing MFGW/LFGW[63] and ranged between 0.37 and 0.75, with a mean value of 0.66 (Table 4.8). Twenty one knees had a value greater than the mean. None of the five variables of the MPFL evaluated had any correlations with the MTGA (Table 4.9).

Table 4.8: Descriptive statistics of the femoral trochlea groove.

Measurement	Mean	Standard Deviation	Minimum	Maximum
The medial facet groove width of the FTG **(MFGW)**	12.04	1.79	8.47	15.09
The lateral facet groove width of the FTG **(LFGW)**	18.42	2.67	12.76	23.57
The altitude of the medial margin **(AMM)**	60.15	4.49	50.29	67.88
The altitude of the lateral margin **(ALM)**	62.42	4.93	52.26	71.25
The altitude of the deepest point **(ADP)**	56.86	4.07	48.74	65.08
The trochlear angle **(α)**	146.64	6.26	134.85	158.58
The depth of the femoral trochlear groove **(DFTG)**	4.43	1.24	2.06	6.46
The trochlear groove asymmetry **(TGA)**	0.66	0.07	0.37	0.75

Table 4.9: The correlation coefficients of the five measurement variables of the MPFL with the femoral trochlear groove.

Variables	MPFLL	MPFLP	MPFLF	MPFLM	MPFLVI
MFGW	**0.664***	0.214	0.319	0.210	-0.087
LFGW	**0.524***	0.179	**0.485***	0.295	-0.078
AMM	**0.566***	0.044	**0.556***	0.160	-0.011
ALM	**0.619***	0.107	**0.511***	0.138	-0.032
ADP	**0.533***	0.075	**0.577***	0.211	0.049
α	-0.416	0.030	0.121	0.222	0.359
DFTG	**0.601***	0.094	0.026	-0.044	0.247
TGA	0.283	0.029	0.066	-0.075	0.111

* Spearman's ranked correlation coefficient **≥ 0.482**

Chapter 5

DISCUSSION

The quadriceps angle (Q-angle), the patellar tendon (PT), the patella and the femoral trochlear groove (FTG) were correlated with five measurements of the medial patellofemoral ligament (MPFL). These measurements included the length (MPFLL), proximal attachment width (MPFLP), femoral insertion width (MPFLF), width in the middle (MPFLM) and the attachment width of the MPFL to the tendon of the vastus intermedius muscle (MPFLVI).

5.1 THE QUADRICEPS ANGLE (Q-ANGLE)

The Q-angle was measured with a goniometer and the resultant values were then correlated with the indicated five measurement values of the MPFL.

The measurement values of the Q-angle ranged between 1.5 degrees and 16.5 degrees, with a mean value of 10.57 degrees (Table 4.1). Stensdotter *et al.*[71], who used the same methodology, reported a mean value of 10.35 degrees which reflects favourably to the mean value reported in this study.

No correlations between the Q-angle and the MPFL were found (Table 4.2). The researcher did not find any references to previous correlation studies between the Q-angle and the MPFL in the literature reviewed.

5.2 THE PATELLAR TENDON

The length (PTL) and both the proximal (PPTW) and distal (DPTW) widths of the patellar tendon were measured with a digital Vernier calliper and the results were then correlated with the previously indicated measurements of the MPFL.

5.2.1 Patellar tendon length (PTL)

The PTL ranged between 34.94mm and 52.97mm and had a mean value of 45.84mm (Table 4.3). The mean PTL value is similar to the mean values reported by Neyret *et al.*[35] (44mm), Reider *et al.*[39] (46mm) and Yoo *et al.*[36] (40.2mm) who measured the PTL from the apex of the patella to the proximal part of the tibial tuberosity. The range is similar to the ranges reported by Yoo *et al.*[36] (31.3mm to 52.6mm) and Reider *et al.*[39] (35mm to 55mm).

Basso *et al.*[29] and Olateju *et al.*[37]however reported far larger mean values of 64.2mm and 69.74mm respectively for the PTL. Basso *et al.*[29] measured the PTL from the apex of the patella to the distal end of its attachment to the tibial tuberosity in a cadaver population. It is therefore clear that Basso *et al.*[29] used a different measurement technique and that may explain the difference between the mean values of the two studies. Olateju *et al.*[37] did not clearly define their measurement parameters and it is therefore not possible to provide a clear explanation for the difference in the mean values.

The PTL correlated positively with both the MPFLL (r_s=0.497) and the MPFLVI (r_s=0.487) (Table 4.4). These positive correlations indicate that as the length of the PTL increases the dimensions of both the MPFLL and MPFLVI also increase (cf. paragraph 5.6). These positive correlations have not been described previously in any of the literature reviewed.

Reider *et al.*[39] reported a negative correlation between the PTL and the maximum width of the MPFL. This finding was not evident in this study. The mean and range of the PTL were similar to the findings of Reider *et al.*[39], although their maximum width measurement of the MPFL was not comparable with this study.

5.2.2 Proximal patellar tendon width (PPTW)

The measurement values of the PPTW in this study were similar to the findings of Yoo *et al.*[36] who used MRI scans, as well as the findings of Basso *et al.*[29] and Andrikoula *et al.*[3], who both used a millimetric ruler in cadaver studies. All the above-mentioned measurements of the PPTW were done at the level of the apex of the patella, and were similar to the measurement description of this study.

The PPTW values ranged between 24.39mm and 36.49mm with a mean value of 30.24mm (Table 4.3). All the measurements in this study were done by means of a digital sliding Vernier calliper. The results obtained were similar to the findings of Yoo *et al.*[36] who reported a range between 23.3mm and 36.8mm, with a mean width value of 30.3mm. This study confirmed both the results of Basso *et al.*[29] and Andrikoula *et al.*[3] who reported mean widths of 31.9mm and 31.2mm respectively. They both used a millimetric ruler for their measurements. It is clear that the PPTW does not exhibit great variability in its measurement values, irrespective of the method used for measurement.

The PPTW correlated positively with both the MPFLL (r_s=0.492) and the MPFLF (r_s=0.489) (Table 4.4). These positive correlations indicate that when the width of the PPTW increases, the dimensions of both the MPFLL and MPFLF will also increase (cf. paragraph 5.6). These positive correlations had not been described previously in any of the literature reviewed.

5.2.3 Distal patellar tendon width (DPTW)

The DPTW in this study was narrower than the PPTW and this is due to the convergence of the fascicles of the patellar tendon towards the tibial tuberosity.[29] This finding corresponds to previous reports.[3,36]

The range of the DPTW was found to be between 19.94mm and 29.38mm, with a mean of 24.37mm (Table 4.3) and were similar to the results found by Yoo *et al.*[36], who reported the range to be between 18.5mm and 30.3mm, with a mean value of 24.0mm in a MRI study. They measured the DPTW at the proximal part of the tibial tuberosity.

Andrikoula *et al.*[3] who used a millimetric ruler in a cadaver study reported the range to be between 24mm and 35mm with a mean value of 27.4mm. It is clear that the measurement values for both the mean and range are slightly larger than the values found in this study. The difference may be explained by their small study sample of ten cadavers, of which seven were male. This may have created a biased result, because males generally tend to be larger than females.

The DPTW correlated positively only with the MPFLF (r_s=0.548) (Table 4.4). This positive correlation indicates that when the width of the DPTW increases the dimension of the MPFLF will also increase (cf. paragraph 5.6). This positive correlation had not been described previously in any of the literature reviewed.

5.3 THE PATELLA

The medial (MFWP) and the lateral (LFWP) facet widths, the articulating surface height (ASHP), the osseous length (OLP) and osseous width (OWP) of the patella were measured and correlated with the MPFL.

5.3.1 Medial facet width of the patella (MFWP)

The MFWP was found to range between 19.07mm and 30.27mm with a mean value of 23.45mm (Table 4.5). The results were similar to the findings of Fucentese *et al.*[43] who reported values that ranged between 12mm and 30mm, with a mean value of 22.82mm by means of MRI scans. They included adolescents in their study which may explain their lower range limit. Dos Santos Netto *et al.*[45] who also used MRI scans, found the MFWP to range between 13.2mm and 28.4mm, with a mean of 18.8mm. Their smaller mean and lower limit values may be due to the inclusion of adolescents because their minimum inclusion age was 14 years. Their upper range limit is, however, similar to this study.

Baldwin and House[41] and Olateju *et al.*[37] reported the mean to be slightly smaller at 20.5mm and 20.38mm respectively. Both measured the MFWP from the most medial border to the median ridge of the patella, alike to the method used in this study.

The MFWP correlated positively with only the MPFLL (r_S=0.572). The positive correlation indicates that when the MFWP increases the MPFLL correspondently increases (cf. paragraph 5.6). No reference to this correlation was made in any of the literature reviewed for the study.

Dos Santos Netto *et al.*[45] did not find any correlation between the MFWP and the MPFLL. Their mean values for both the MFWP and MPFLL were smaller than the values reported for in this study. This may explain the difference in results.

5.3.2 Lateral facet width of the patella (LFWP)

The LFWP was found to range between 21.95mm and 31.19mm, with a mean value of 26.93mm (Table 4.5). These values are similar to the mean values found by both Olateju *et al.*[37] (mean = 26.02mm) and Baldwin and House[41] (mean = 27.5mm) who measured the LFWP from the lateral border of the patella to its median ridge. Olateju *et al.*[37] used cadaver material for their measurements, whilst Baldwin and House[41] did their measurements during arthroplasty of the knee.

The range and mean of the LFWP were similar to the values reported for MRI scans by Fucentese *et al.*[43]. They reported a range between 20mm and 31mm with a mean LFWP value of 25.5mm. Dos Santos Netto *et al.*[45] reported a range of 17.6mm to 28.5mm with a mean LFWP value of 23.8mm for MRI scans. Although their measurement values were slightly smaller than the values found in this study, they were still within an acceptable range.

This study found no correlation between the LFWP and the five measurement variables of the MPFL. Dos Santos Netto *et al.*[45], similar to this study, could not demonstrate any correlations.

5.3.3 Articulating surface height of the patella (ASHP)

The range of the ASHP was found to be between 28.66mm and 39.44mm, with a mean value of 33.32mm (Table 4.5). These measurement values were similar to the results found by Yoo *et al.*[36] and Baldwin and House[41] who both used a similar measurement technique for the ASHP.

The range and mean value of the ASHP in this study was similar to that reported for MRI scans.[36] Yoo *et al.*[36] reported a range between 27.2mm and 40.6mm, with a mean ASHP value of 32.9mm.

Baldwin and House[41] reported a range between 28mm and 47mm, with a mean value of 35.7mm, by using a calliper for their measurements. Although their range is slightly larger than reported in this study, their mean was similar. Reider *et al.*[39] reported a range of 30mm to 39mm, with a mean ASHP value of 35mm by using a millimetric ruler. The range and mean reported by Reider *et al.*[39] was similar to this study.

It is clear that the ASHP does not exhibit great variability in measurement values irrespective of the method used to obtain the measurement.

The ASHP correlated positively with the MPFLL (r_s=0.709). The positive correlation of the ASHP with the MPFLL, indicates that when the ASHP increases the MPFLL correspondently increases (cf. paragraph 5.6). This positive correlation has not been described in any of the literature reviewed.

5.3.4 Osseous width of the patella (OWP)

The OWP was measured in a linear line from the lateral to medial border of the patella, and this measurement was found to range between 38.11mm and 52.95mm with a mean value of 44.55mm (Table 4.5). Olateju *et al.*[37] used a similar measurement description and reported a mean OWP value of 45.14mm in a cadaver sample. The results of this study were in accordance with both the results of Basso *et al.*[29] (mean = 45.7mm) in a cadaver population and Yoo *et al.*[36] (mean = 45.8mm; range = 36.5mm to 53.9mm) who used MRI scans.

Fucentese *et al.*[43] reported an OWP range between 32mm and 50mm, with a mean OWP value of 42mm. Their minimum range value and mean were slightly smaller than the values reported in this study, but still fell within acceptable parameters. Baldwin and House[41] (mean = 46.1mm; range = 36mm to 65mm) and Reider *et al.*[39] (mean = 47mm; range = 40mm to 55mm) both reported mean values slightly larger than the values reported in this study, but were still within an acceptable range. Baldwin and House[41] did their measurements during knee arthroplasty and Reider *et al.*[39] on cadavers.

The OWP correlated positively with the MPFLF (r_s=0.488). The positive correlation found between the OWP and the MPFLF indicates that when the width of the PPTW increases, the latter also increases (cf. paragraph 5.6). This positive correlation has not been described previously in any of the literature reviewed.

5.3.5 Osseous length of the patella (OLP)

The range of the OLP was found to be between 36.27mm and 51.66mm with a mean value of 42.93mm (Table 4.5). The results were similar to the findings of Olateju *et al.*[37] (mean = 43.73mm) and Basso *et al.*[29] (mean = 43mm) who respectively used a Vernier calliper and a transparent ruler in cadaver studies.

Yoo *et al.*[36] used MRI scans to measure the OLP and found the range to be between 34.1mm and 52.3mm, with a mean value of 44.6mm. Reider *et al.*[39] found the OLP to have a range between 38mm and 53mm with a mean value of 45mm. Both means were slightly larger than the value reported in this study, but were still within an acceptable range when compared to this study.

All the above mentioned studies defined the OLP to extent from the superior border of the patella to its apex. The results suggested that the measurement value of the OLP does not exhibit great variability, irrespective of the measurement technique or instrument of measurement.

The OLP correlated positively with both the MPFLL (r_s=0.590) and the MPFLF (r_s=0.587) (Table 4.6). These positive correlations between the OLP and both the measurement variables of the MPFL, the MPFLL and the MPFLF, indicate that when the width of the OLP increases, the parameters of both the latter mentioned parameters would also increase (cf. paragraph 5.6). These positive correlations had not been described previously in any of the literature reviewed.

5.4 THE MEDIAL PATELLOFEMORAL LIGAMENT (MPFL)

The MPFL can be described as a sail-like structure stretching between the medial femoral condyle and the medial side of the patella, with the patellar insertion wider than the femoral insertion.

The MPFL was exposed by using a posterior approach and a total of five morphological measurements were obtained. These measurements included the length (MPFLL), the proximal attachment width (MPFLP), the femoral attachment width (MPFLF), the middle width (MPFLM) and finally the attachment width of the MPFL to the tendon of the vastus intermedius muscle (MPFLVI).

In all cases the patellar insertion was found to extend up to the aponeurotic fibres of vastus intermedius muscle and is similar to previous findings.[54,59]

According to the majority of studies, the MPFL is an almost constant clinical entity found in the knee.[4,5,16,49–51,53–58,75] However, Reider *et al.*[39] only found the MPFL to be present in 35% of dissected knees.[39] In the present study the MPFL was present in 97% of the dissected knees. Conlan *et al.*[6] and Aragão *et al.*[52] found the MPFL to be present in the majority of knees at 94% and 88% respectively.

The attachment of the MPFL to the tendon of the vastus intermedius muscle (MPFLVI) was already described as early as 1880[47], but has been sparsely reported in the literature. Both Conlan *et al.*[6] and Aragão *et al.*[52] referred to this attachment of the MPFL to the vastus intermedius tendon. Aragão *et al.*[52] reported that this attachment was only present in 7% of the knees they dissected. Conlan *et al.*[6] described this attachment, but no further details were given. The attachment of the MPFL to the aponeurotic fibres of the vastus intermedius muscle was present in all the knees dissected in this study. The reason why the findings of this study differ from previous studies may be due to the dissection technique used. This study used a posterior approach similar to Mochizuki *et al.*[54] that entails reflecting the patella medially to expose the MPFL, while the other studies only used an anterior approach.

5.4.1 Medial patellofemoral ligament attachment width on the vastus intermedius tendon (MPFLVI)

The measurement values of the MPFLVI were similar to the values obtained by Mochizuki *et al.*[54] and Kikuchi *et al.*[59] who both exposed the MPFL using the posterior approach that is in accordance to this study.

The MPFLVI attachment was found to range between 18.02mm and 35.42mm, with a mean value of 25.65mm (Table 4.7). The mean obtained in this study was similar to the finding of Mochizuki *et al.*[54] (mean = 24.3mm) and Kikuchi *et al.*[59] (mean = 28.5; range = 11.0mm to 33.4mm). The mean reported by Kikuchi *et al.*[59] was slightly larger compared to this study, but is still within an acceptable range. A reason for this difference may be that they used three dimensional images to obtain the measurement values, while in this study a digital sliding Vernier calliper was used.

This attachment of the MPFL to the vastus intermedius led Conlan *et al.*[6] to conclude that the MPFL has a double fibre bundle organisation. The proximal fibres insert on the posterior surface of the vastus medialis oblique muscle and the aponeurotic fibres of the vastus intermedius muscle, whilst the distal fibres insert on the medial border of the patella.[6] The double fibre organisation described by Conlan *et al.*[6] was supported by the findings of this study.

5.4.2 Proximal attachment width of the medial patellofemoral ligament (MPFLP)

The MPFLP was found to range between 41.18mm and 66.50mm, with a mean value of 49.82mm (Table 4.7). These findings were dissimilar to results previously reported in literature. Steensen *et al.*[56] reported a range of 14mm to 20mm with a mean value of 17mm, while Baldwin[16] reported a range between 16mm and 38mm with a mean value of 28.2mm. The MPFLP values of both Steensen *et al*.[56] and Baldwin[16] were much smaller than the values reported in this study. A reason for this difference may be that they used an anterior approach to expose and measure the MPFLP, while this study used a posterior approach. In this study the MPFLP included the attachment to both the patella and the tendon of the vastus intermedius muscle.

Placella *et al.*[55] exposed the ligament from the posterior surface, and reported a mean value of 24.5mm. Their mean value is smaller than the mean value reported in this study. They did not find the attachment of the MPFL to the vastus intermedius muscle tendon present in all the knees they dissected. This may explain the larger mean value found in this study compared to their findings.

By subtracting the MPFLVI from the MPFLP value found in this study, to determine the patellar attachment length, a range between 12.58mm and 31.08mm with a mean value of 24.17mm was found and these values were well within the acceptable mean and range values previously reported for the attachment width of the MPFL to the patella.[4,55,58]

5.4.3 Length of the medial patellofemoral ligament (MPFLL)

The reported values for the MPFLL were either determined from dissections[16,57,75] or from MRI scans.[45,60] Two dissection techniques were used to expose the MPFL; either an anterior approach[51,57,76] or a posterior approach.[54,55,59]

Both the MPFLL range (54.27mm to 77.03mm) and mean value of 67.53mm (Table 4.7) were similar to the findings of LaPrade *et al*.[75] (mean = 65.2mm; range = 56.8mm to 77.8mm), who obtained their measurements from fresh-frozen cadaver knees. In a cadaver study Baldwin[16] reported a slightly smaller mean value (59.8mm), but the range was similar (50mm to 75mm) to this study. Both the aforementioned studies used an anterior approach to expose the MPFL.

Mochizuki *et al.*[54] reported a mean length of 56.3mm while Placella *et al.*[55] reported a mean length of 72mm. Both these studies used a posterior approach to expose the MPFL, similar to this study. Mochizuki *et al.*[54] measured the transverse length of the MPFL, while Placella *et al.*[55] measured the MPFLL along the longest border of the MPFL. This study measured the length from the centre of the femoral attachment to the centre of the proximal attachment. This may explain the difference in the results obtained.

Tuxøe *et al.*[49] reported the MPFLL range between 45mm and 64mm with a mean value of 53mm and Panagiotopoulos *et al.*[4] reported a range between 45mm and 50mm, with a mean value of 47.37mm. They both measured the MPFLL from different bony landmarks on the femur. Tuxøe *et al.*[49] measured it from the centre of the adductor tubercle and Panagiotopoulos *et al.*[4] from the medial femoral epicondyle. Both measurement parameters were different from the ones applicable to this study. An anterior approach to expose the MPFL was used in both studies, compared to a posterior approach in this study. The difference in approach, with the difference in measuring technique, may explain the difference in the values when compared to this study.

Dos Santos Netto *et al.*[45] (mean = 46.4mm; range = 38.8mm to 57.9mm) and De Oliveira *et al.*[60] (mean = 49.04; range = 36.1mm to 61.8mm) both used MRI scans for the MPFLL measurements. Both these studies reported a mean and range of smaller than the values reported in this study. De Oliveira *et al.*[60] stated that when using MRI scans for measurement, some approximations are needed to measure the length due to the curvature of the MPFL. This may explain the difference in the findings compared to a posterior dissection method.

5.4.4 Middle width of the medial patellofemoral ligament (MPFLM)

The MPFLM was found to range between 13.52mm and 34.96mm, with a mean value of 24.02mm. Nomura *et al.*[53] found the MPFLM to have a mean of 12mm similar to that of Viste *et al.*[51] (mean = 12 mm; range = 6.0 to 16.00). Aragão *et al.*[52] reported a range between 14.0mm and 27.5mm with a mean value of 20.2mm. The MPFLM measurement is dependent on the MPFLL measurement. Aragão *et al.*[52], Nomura *et al.*[53] and Viste *et al.*[51] reported a mean MPFLL of 55.6mm, 58.8mm and 59mm respectively by using an anterior approach. This is smaller than the mean

MPFLL reported in this study. The difference in approach may explain the difference in the reported measurements of the MPFLM.

Placella *et al.*[55] used a posterior approach, similar to this study, but reported a mean MPFLM value of 10.5mm. This was smaller than the value reported in this study. Similar to this study, Placella *et al*.[55] used a posterior approach to expose the MPFL; while the current study did not clear the first layer from the MPFL. This may explain the difference in the results.

5.4.5 Femoral attachment width of the medial patellofemoral ligament (MPFLF)

The MPFL tapers from its patellar attachment to its insertion on the femur. The MPFLF was found to range between 7.59mm and 25.26mm, with a mean value of 14.70mm. This was similar to the results obtained by Panagiotopoulos *et al.*[4] (mean = 14.87mm; range = 10mm to 20mm) and Steensen *et al.*[56] (mean = 15.4mm; range = 11mm to 20mm). Both these studies used an anterior approach to expose the MPFL in cadaver studies. Aragão *et al.*[52] reported a MPFLF value that ranged between 10mm and 28.8mm, with a mean value of 17.1mm. Their mean was slightly larger than the mean reported in this study, but the range was similar. Tuxøe *et al.*[49] reported a mean width of 19mm and a range between 10mm and 30mm. Their range was comparable, but the mean was slightly larger than the values reported in this study. The reason for this difference may be that they measured the MPFLF one centimetre from the femoral attachment, which is different to the measurement method used in this study.

Baldwin[16] (mean = 10.6mm; range = 6mm to 15mm), and Viste *et al.*[51] both reported ranges and mean values that were smaller (mean = 8.8mm; range = 5mm to 14mm) than the values reported in this study. The difference in reported values may be due to the anterior dissection approach they used, compared to this study where a posterior approach was used. In an anterior approach it was difficult to clearly identify the MPFLF because dissection was only possible 10-20mm from the adductor tubercle[4], while with the posterior approach the full extent of the MPFLF was clearly visible.[54] This may explain the difference in reported findings compared to this study.

Placella *et al.*[55] used a posterior approach to expose the ligament, similar to this study, but they reported the MPFLF to have a mean of 8.9mm. This was smaller than the mean value reported in this study. Placella *et al.*[55] removed the first and third layer from the MPFL in the second layer, while this study only removed layer three from the MPFL. This may explain the difference in the results.

5.5 THE FEMORAL TROCHLEAR GROOVE

The medial (MFGW) and lateral (LFGW) facet groove widths of the FTG, the altitude of the medial (AMM) and lateral (ALM) margins of the medial and lateral condyles, the maximum altitude of the deepest point (ADP) and the trochlear angle (α) of the FTG were photometrically measured and correlated with the MPFL.

Both the depth of the FTG (DFTG) and the trochlear groove asymmetry (TGA) were determined mathematically and the values were then correlated with the MPFL.

5.5.1 Medial facet groove width (MFGW) of the FTG

The MFGW values were found to range between 8.47mm and 15.09mm, with a mean value of 12.04mm (Table 4.8). This result was similar to that of Wanner[66] who reported a mean value of 11.31mm and who also used a photometric approach, similar to this study.

The MFGW correlated positively with the MPFLL (r_s=0.664) (Table 4.9). This positive correlation indicates that when the width of the DPTW increases the dimension of the MPFLL will also increase (cf. paragraph 5.6). This positive correlation was not described previously in any of the literature reviewed.

5.5.2 Lateral facet groove width (LFGW) of the FTG

The LFGW was measured from the deepest point of the FTG to the most prominent margin of the lateral femoral condyle. This was similar to the measurement description of Wanner.[66] The LFGW was found to range between 12.76mm and 23.57mm, with a mean value of 18.42mm (Table 4.8). Wanner[66] reported a mean value of 22.89mm, slightly larger than the value reported in this study. The reason for this difference is unclear, since similar measuring techniques were applied.

The LFGW correlated positively with both the MPFLL (r_s=0.524) and the MPFLF (r_s=0.485) (Table 4.9). These positive correlations indicate that when the width of the LFGW increases the dimensions of both the MPFLL and MPFLVI will also increase (cf. paragraph 5.6). These positive correlations have not been described in any of the literature reviewed.

5.5.3 Altitude of the medial margin (AMM) of the medial condyle of the femur

The measurement values of the AMM were found to range between 50.29mm and 67.88mm, with a mean value of 60.15mm (Table 4.8). This was similar to measurements obtained by MRI[65] scans and photometrically.[66] Charles *et al.*[65] reported a mean value of 58.77mm by using MRI scans and Wanner[66] reported a mean of 58.45mm using photometrics. Similarly, Dos Santos Netto *et al.*[45] reported an AMM measurement value that ranged between 50.9mm and 62.4mm, with a mean value of 56.5mm using MRI scans. Their mean was slightly smaller compared to this study, but is still within acceptable parameters.

It is clear that the AMM does not exhibit a great variability in measurement values irrespective of the method used to obtain the measurement.

The AMM correlated positively with both the MPFLL (r_s=0.566) and the MPFLF (r_s=0.556) (Table 4.9). These positive correlations of the AMM with both the MPFLL and the MPFLF indicate that when the AMM increases, both the MPFLL and MPFLF increase correspondingly (cf. paragraph 5.6). These correlations were not previously reported in the literature reviewed.

Dos Santos Netto *et al.*[45] found no correlation between the AMM and the MPFL. Their AMM values were similar, but the reported values for the MPFLL were not comparable to this study. This may explain the difference in results found compared to this study.

5.5.4 Altitude of the lateral margin (ALM) of the lateral condyle of the femur

The ALM was measured from the posterior condyle tangent line to the most prominent margin of the lateral femoral condyle, and was found to range between 52.26mm and 71.25mm, with a mean value of 62.42mm (Table 4.8). These results corresponded to the results obtained by MRI scans[45] and by photometric analysis.[66] Dos Santos Netto *et al.*[45] reported the ALM value to range between 51.5mm and 70.7mm, with a mean value of 62.6mm obtained from MRI scans, while Wanner[66] reported a mean value of 62.09mm by using photometrics. The results obtained by both aforementioned researchers were similar to the findings of this study. Charles *et al.*[65] reported a slightly larger ALM mean value (63.94mm) by using MRI scans. However, the results were still within acceptable parameters. It is clear that the ALM does not exhibit great variability in measurement values irrespective of the method used to obtain the measurement.

The ALM correlated positively with both the MPFLL (r_s=0.619) and the MPFLF (r_s=0.511) (Table 4.9). The positive correlations of the ALM with both the MPFLL and the MPFLF indicate that when the ALM increases, both the MPFLL and MPFLF increase correspondingly (cf. paragraph 5.6). These correlations were not reported previously in any of the reviewed literature.

Dos Santos Netto *et al.*[45] found no correlation between the ALM and the MPFL. Their ALM values were similar, but the reported value for the MPFLL was not comparable to this study. This may explain the difference in the results obtained.

5.5.5 Altitude of the deepest point of the femoral trochlear groove (ADP)

The ADP was measured from the deepest part of the FTG to the posterior condyle tangent line, similar to Wanner[66], and the measurement value was found to range between 48.74mm and 65.08mm, with a mean value of 56.86mm (Table 4.8). The mean value corresponded well with the results of Wanner[66] who reported a mean of 55.77mm using photometrics.

The ADP positively correlated with both the MPFLL (r_s=0.533) and the MPFLF (r_s=0.577) (Table 4.9). The positive correlations of the ADP with both the MPFLL and the MPFLF indicate that when the ADP increases both the MPFLL and MPFLF increase correspondingly (cf. paragraph 5.6). These correlations were not previously reported with respect to the literature reviewed.

5.5.6 Trochlear angle

The trochlear angle is defined as the angle from the deepest part of the FTG to the most prominent margin of the medial and lateral condyles respectively, in accordance with the measurement descriptions of Wanner[66], Glard *et al.*[68] and Shih *et al.*[67] who either used MRI scans[67,68] or photometrics.[66] The trochlear angle was found to range between 134.85 degrees and 158.58 degrees, with a mean value of 146.64 degrees (Table 4.8).

The results obtained corresponded well with the findings of Dos Santos Netto *et al.*[45] (mean = 146.1 degrees; range = 133.0 degrees to 171.0 degrees) by means of MRI scans and the results of Shih *et al.*[67] (mean = 146.1 degrees; range = 126.0 degrees to 165.0 degrees) using photometrics. The results of this study confirmed the findings of Wanner[66] and Charles *et al.*[65] who reported a mean trochlear angle of 147.93 degrees by means of photometrics and 148.48 degrees by means of MRI scan measurements respectively. It is clear from the results that the mean trochlear angle value corresponded well with each other regardless of the measurement technique used, MRI or photometric analysis.

This study found no correlation between the trochlear angle and the five measurement variables of the MPFL. Dos Santos Netto *et al.*[45], similar to this study, found no correlation.

5.5.7 Depth of the femoral trochlear groove (DFTG)

The DFTG is formulated as (AMM + ALM)/2 – ADP[64] and was found to range between 2.06mm and 6.46mm, with a mean DFTG value of 4.43mm (Table 4.8). The DFTG in this study corresponded well with the depth values reported by both MRI scans[45] and photometric measurements.[66] Both the mean and range were similar to the results found by Dos Santos Netto *et al.*[45] (mean = 4.2mm; range = 0mm to 7.3mm) measured by MRI scans and Wanner[66] (mean = 4.5mm) by means of photometrics.

Pfirrmann *et al.*[62] found slightly larger values compared to this study, with a mean of 5.2mm and a range between 2.4mm to 10.5mm by using MRI scans, but the parameters were still within an acceptable range. Charles *et al.*[65] used MRI scans and reported a mean value of 6.2mm. They determined the DFTG by drawing a line across the anterior margins of the medial and lateral condyle and measured the distance from the centre of this line to the deepest point of the FTG. They used a different technique to determine the trochlear depth and this may explain the difference in the findings compared to this study.

The DFTG positively correlated with the MPFLL (r_s=0.601) (Table 4.9). The positive correlation of the DFTG with the MPFLL indicate that when the DFTG increases the MPFLL increases correspondingly (cf. paragraph 5.6). This positive correlation was not previously reported in the reviewed literature.

Dos Santos Netto *et al.*[45] found no correlation between the DFTG and the MPFL. Their DFTG values were similar to this study, but the reported value for the MPFLL was not comparable. This may explain the difference in the results obtained.

5.5.8 Trochlear groove asymmetry (TGA)

The TGA is mathematically determined by dividing the MFGW by the LFGW.[64] Values for the TGA ranged between 0.37 and 0.75, with a mean value of 0.66 (Table 4.8). The TGA has been sparsely reported in the literature, and has only been studied with MRI scans.[62,65] Pfirrmann *et al.*[62] reported a range between 0.17 and 0.96, with a mean value of 0.57. Their mean is slightly smaller in comparison to this study. Balcarek *et al.*[63] reported a smaller mean value of 0.359 when compared to this study. This difference may be due to a difference in measurement technique, because this study used photometrics to determine the TGA value.

No correlations between the TGA and the MPFL were found (Table 4.9). No references to previous correlation studies pertaining to the TGA and the MPFL in the literature reviewed could be found.

5.6 INTERPRETATION OF THE CORRELATIONS

All the correlations in this study were found to be positive. These correlations may emphasise the interdependency that exists among the components of the joint. The components of the PFJ synergistically increases in size to keep the harmonious stability within the joint. Disruptions of the balance, either from pathology or reconstructive surgery, may alter the delicate harmony within the joint.

Chapter 6

CONCLUSION

This study entailed the analysis of correlations between the morphology of the medial patellofemoral ligament (MPFL) and specific morphological features of the Quadriceps-angle (Q-angle), the patella, the patellar tendon and the geometry of the femoral trochlear groove (FTG) in knees with a stable patellofemoral joint (PFJ). The analysis of these correlations followed a detailed description of the morphology of the MPFL.

6.1 OVERVIEW

The knee is an intricate structure. It is one of the most composite joints in the human body and often involved in either injury, pain, pathology or a combination of the aforementioned. The knee consists of three joints; the tibiofemoral joint, the tibiofibular joint and the patellofemoral joint (PFJ).[12] The PFJ has lately received increased interest from a clinical perspective, especially in regard to treating lateral patellar dislocation.[77]

The PFJ is dynamic in nature and consists of several soft tissues and osseous structures.[2] Instability of the PFJ may lead to subluxation and/or lateral dislocation of the patella.[1] The medial patellofemoral ligament (MPFL) has been biomechanically identified to be the main medial static stabiliser to prevent lateral patellar dislocation.[4–6] To understand instability, focus should be shifted to the harmony within a stable PFJ. Stability is defined as resistance to displacement away from the stable position of equilibrium where all forces are in balance.[2] There are various structures that contribute to stability of the PFJ and these include osseous components and the soft tissue structures of the joint. Some of the structures that contribute to stability of the PFJ synergistically with the MPFL, include the Q-angle, the patellar tendon, the patella and the femoral trochlear groove (FTG).[2] These structures generate forces that act on the PFJ during normal flexion and extension and are in a harmonious balance in the stable PFJ.[2] This makes it imperative to understand the relationship between the different components.

Slight differences of the MPFL are present in the stable PFJ. The MPFL has variations regarding the extent of the attachments of the ligament, the length of the ligament and the width thereof. The focus of this study was to describe how these morphologic differences correlate with other elements of the PFJ that also contribute toward stability.

6.2 AIM AND OBJECTIVES

The aim of this study was to observe and measure certain anatomical variations of the osseous components and soft tissue structures in a stable PFJ and determine how these correlate with the morphology of the MPFL. To reach this aim, two objectives were pursued:

1. To describe the morphometry of the Q-angle, patellar tendon, patella, MPFL and the femoral trochlear groove.

2. Finding correlations between the morphology of the MPFL and the other structures in the knee that collectively contribute to stability of the PFJ.

The different structures were morphometrically measured on 33 cadaver knees to determine if a relationship does in fact exist. The methods incorporated dissection, determining the Q-angle with a goniometer, morphometric measurements with a digital sliding Vernier calliper and photo metrics. The collected data were also compared to previous published morphometric measurements.

The data collected were statistically analysed by means of the Spearman’s rank correlation coefficient to ascertain the correlation. This correlation entails ranking the data to determine the monotonic relationship. The correlations between the MPFL and the other structures were reported and further discussed.

6.3 MAIN FINDINGS

The <u>length of the MPFL (MPFLL)</u> correlated with eleven different measurements of the patellar tendon, the patella and the FTG. Two measurements of the patellar tendon correlated with the MPFLL; this includes the proximal width and the length of the patellar tendon (cf. Table 4.4). Three measurements of the patella correlated with the MPFLL. These include the medial facet width, the articulating height and the osseous length of the patella (cf. Table 4.6). The MPFLL positively correlated with all the osseous measurements of the FTG, this includes the mathematically derived depth of the FTG (cf. Table 4.9).

The femoral attachment width of the MPFL (MPFLF) correlated with eight different measurements. It correlated with both the proximal and distal widths of the patellar tendon (cf. Table 4.4), the osseous width and length of the patella (cf. Table 4.6) and with four bony measurements of the FTG (cf. Table 4.9). These measurements included the lateral patellar groove width, both the medial and lateral altitudes of the respective condyles, and the altitude of the deepest point of the FTG.

The width of the attachment of the MPFL to the vastus intermedius tendon only correlated with the length of the patellar tendon (cf. Table 4.4).

The anatomy of the MPFL was found to be fan-shaped in all the knees. The proximal attachment of the MPFL attached to the medial border of the patella and to the tendon of the vastus intermedius muscle. The latter attachment was present in all the knees dissected.

This study supports the argument that the PFJ is in a harmonious balance.[2] In a stable PFJ, the various components synergistically contribute to this stability.[2] This underlines that components within the stable PFJ are related proportionally to each other.

6.4 RESEARCH LIMITATIONS

This study was limited to measurements attained by dissection and physical measurements. The methodology was scrutinised by the researcher to ensure accuracy and repeatability. It should be noted that this study used dissections and measuring techniques that were previously documented and tested to ensure that sound techniques were used. .

The sample consisted of mainly Black cadavers from the University of the Free State, limiting the population composition of this study. However the study did not aim to distinguish between various ethnicities but rather to assert the existing relationship between the MPFL and other components of the PFJ.

The sample of this study included more male (n = 19) than female knees. Males tend to be bigger than their female counterparts. This may have increased the upper limit of the ranked data. However, this does not influence the correlations found in this study with Spearman's ranked correlation coefficient.

The study was limited to a cadaver population and the histories with regard to stability of the knees were unknown. This study excluded knees that had obvious pathology or indications of knee surgery present. It was assumed that knees that fit the inclusion criteria were knees that were stable in nature. This did not influence the aim of the study which was to relate the MPFL to other components of the PFJ.

Limited comparisons between the findings of this study and past research could possibly be due to the limited published literature on correlations of the MPFL with other structures.

6.5 RECOMMENDATIONS

The methods discussed below were used in this study and yielded good results. The following are therefore recommended for future studies in this regard.

6.5.1 Exposure of the MPFL

The exposure of the MPFL entailed first identifying the superior border of the MPFL before posterior dissection commenced (cf. paragraph 3.5). This approach safely and effectively exposed the MPFL. This ensured that part of the ligament was always visible as a reference point and "blind" dissection was avoided. This is different from the anterior approach where the different layers form complex connections between them that could make accurate exposure of the MPFL challenging.[16]

6.5.2 Geometry of the FTG

It is recommended to photograph the distal end of the femur before it starts to dry out and the white hyaline cartilage of the trochlear groove starts to darken. This will ensure the best contrast on the photographs. This was achieved by photographing the distal end of the femur either directly after removal from the cadaver, or keeping the distal end moist until the photograph could be taken.

6.6 CONCLUDING REMARKS

This study is unique, as it is the first study to correlate the morphology of the MPFL with other structures in the knee in a South African population. International research regarding these correlations were rather limited. The study offers valuable insight into the interdependency of the different components within the PFJ and confirms that the morphology of the MPFL forms part of this balance. Reconstructive surgery of the MPFL to restore stability to the knee after lateral patellar dislocation is a favourite among orthopaedic surgeons.[77–80] The findings of this study suggest that the MPFL synergistically forms part of this balance within the PFJ. It is therefore important to understand how the morphology of the MPFL relates to the joint. The findings of this study suggest that the morphology of the MPFL may be an important factor to consider before this ligament is reconstructed and replaced. The anatomical findings of this study in regard to the morphology of the MPFL suggest that the description of the proximal attachment should include both the patellar insertion and the insertion to the vastus intermedius tendon.

REFERENCES

1. Elliott, C. C. & Diduch, D. R. Biomechanics of patellofemoral instability. *Oper. Tech. Sports Med.* **9,** 112-121 (2001).
2. Amis, A. A. Current concepts on anatomy and biomechanics of patellar stability. *Sports Med. Arthrosc.* **15,** 48-56 (2007).
3. Andrikoula, S., Tokis, A., Vasiliadis, H. S. & Georgoulis, A. The extensor mechanism of the knee joint: an anatomical study. *Knee Surg. Sports Traumatol. Arthrosc.* **14,** 214-220 (2006).
4. Panagiotopoulos, E., Strzelczyk, P., Herrmann, M. & Scuderi, G. Cadaveric study on static medial patellar stabilizers: the dynamizing role of the vastus medialis obliquus on medial patellofemoral ligament. *Knee Surg. Sports Traumatol. Arthrosc.* **14,** 7-12 (2006).
5. Desio, S. M., Burks, R. T. & Bachus, K. N. Soft Tissue Restraints to Lateral Patellar Translation in the Human Knee. *Am. J. Sports Med.* **26,** 59-65 (1998).
6. Conlan, T., Garth, W. P. & Lemons, J. E. Evaluation of the medial soft-tissue restraints of the extensor mechanism of the knee. *J. Bone Joint Surg. Am.* **75,** 682-693 (1993).
7. Jackson, A. M. Anterior knee pain. *J. Bone Joint Surg. - Br. Vol.* **83,** 937-948 (2001).
8. Fithian, D. C. & Nomura, E. Anatomy of patellar dislocation in *Anterior knee pain and patellar instability* 77-92 (Springer London, 2006). doi:10.1053/otsm.2001.25573
9. Waryasz, G. R. & McDermott, A. Y. Patellofemoral pain syndrome (PFPS): a systematic review of anatomy and potential risk factors. *Dyn. Med.* **7,** 1 (2008).
10. Minkowitz, R., Inzerillo, C. & Sherman, O. H. Patella instability. *Bull. NYU Hosp. Jt. Dis.* **65,** 280-293 (2007).
11. Farahmand, F., Tahmasbi, M. N. & Amis, A. A. The contribution of the medial retinaculum and quadriceps muscles to patellar lateral stability – an in-vitro study. *Knee* **11,** 89-94 (2004).

12. Moore, K. L., Dalley, A. F. & Agur, A. M. *Clinically Oriented Anatomy*. (Lippincott Williams & Wilkins, 2014). doi:10.1002/ca.22316

13. Bicos, J., Fulkerson, J. P. & Amis, A. A. Current concepts review: the medial patellofemoral ligament. *Am. J. Sports Med.* **35,** 484-492 (2007).

14. Merican, A. M. & Amis, A. A. Anatomy of the lateral retinaculum of the knee. *Bone Joint J.* **90,** 527-534 (2008).

15. Warren, L. F. & Marshall, J. L. The supporting structures and layers on the medial side of the knee: an anatomical analysis. *J. Bone Joint Surg. Am.* **61,** 56-62 (1979).

16. Baldwin, J. L. The anatomy of the medial patellofemoral ligament. *Am. J. Sports Med.* **37,** 2355-61 (2009).

17. Feller, M. J., Feagin Jr, J. A. & Garrett Jr, W. E. The medial patellofemoral ligament revisited: an anatomical study. *Knee Surg. Sports Traumatol. Arthrosc.* **1,** 184-186 (1993).

18. Colvin, A. C. & West, R. V. Patellar instability. *J. Bone Joint Surg. Am.* **90,** 2751-62 (2008).

19. Cooke, D., Scudamore, A., Li, J., Wyss, U., Bryant, T. & Costigan, P. Axial lower-limb alignment: comparison of knee geometry in normal volunteers and osteoarthritis patients. *Osteoarthr. Cartil.* **5,** 39-47 (1997).

20. Brattström, H. Shape of the intercondylar groove normally and in recurrent dislocation of the patella. A clinical and x-ray anatomical investigation. *Acta Orthop. Scand.* **35,** 1-148 (1964).

21. Livingston, L. A. The quadriceps angle: a review of the literature. *J. Orthop. Sports Phys. Ther.* **28,** 105-109 (1998).

22. Smith, T. O., Hunt, N. J. & Donell, S. T. The reliability and validity of the Q-angle : a systematic review. *Knee Surg. Sports Traumatol. Arthrosc.* **16,** 1068-1079 (2008).

23. Insall, J., Falvo, K. A. & Wise, D. W. Chondromalacia patellae. A prospective study. *J. Bone Joint Surg. Am.* **58,** 1-8 (1976).

24. Veeramani Raveendranath, S. N., Sujatha, N., Priya, R. & Rema, D. The Quadriceps angle (Q angle) in Indian men and women. *Eur. J. Anat.* **13,** 105-109 (2009).

25. Schulthies, S. S., Francis, R. S., Fisher, A. G. & Van de Graaff, K. M. Does the Q angle reflect the force on the patella in the frontal plane? *Phys. Ther.* **75,** 24-30 (1995).

26. Guerra, J. P., Arnold, M. J. & Gajdosik, R. L. Q-Angle: Effects of Isometric Quadriceps Contraction and Body Position. *J. Orthop. Sports Phys. Ther.* **19,** 200-204 (1994).

27. Omololu, B. B., Ogunlade, O. S. & Gopaldasani, V. K. Normal Q-angle in an adult Nigerian population. *Clin. Orthop. Relat. Res.* **467,** 2073-6 (2009).

28. Maharjan, R., Shrestha, B. P., Khanal, G. P., Chaudhary, P. & Karn, N. K. Quadriceps angle in eastern Nepalese population. *Heal. Renaiss.* **11,** 150-156 (2013).

29. Basso, O., Johnson, D. P. & Amis, A. A. The anatomy of the patellar tendon. *Knee Surg. Sports Traumatol. Arthrosc.* **9,** 2-5 (2001).

30. Insall, J. & Salvati, E. Patella Position in the Normal Knee Joint 1. *Radiology* **101,** 101-104 (1971).

31. Dejour, H., Walch, G., Nove-Josserand, L. & Guier, C. H. Factors of patellar instability: an anatomic radiographic study. *Knee Surg. Sports Traumatol. Arthrosc.* **2,** 19-26 (1994).

32. Shabshin, N., Schweitzer, M. E., Morrison, W. B. & Parker, L. MRI criteria for patella alta and baja. *Skeletal Radiol.* **33,** 445-450 (2004).

33. Lancourt, J. E. & Cristini, J. A. Patella alta and patella infera. Their etiological role in patellar dislocation, chondromalacia, and apophysitis of the tibial tubercle. *J. Bone Joint Surg. Am.* **57,** 1112-1115 (1975).

34. Davies, A. P., Costa, M. L., Donell, S. T., Glasgow, M. M. & Shepstone, L. The sulcus angle and malalignment of the extensor mechanism of the knee. *Bone Joint J.* **82,** 1162-1166 (2000).

35. Neyret, P., Robinson, A. H. N., Le Coultre, B., Lapra, C. & Chambat, P. Patellar tendon length – the factor in patellar instability? *Knee* **9,** 3-6 (2002).

36. Yoo, J. H., Yi, S. R. & Kim, J. H. The geometry of patella and patellar tendon measured on knee MRI. *Surg. Radiol. Anat.* **29,** 623-628 (2007).

37. Olateju, O. I., Philander, I. & Bidmos, M. A. Morphometric analysis of the patella and patellar ligament of South Africans of European ancestry. *S. Afr. J. Sci.* **109,** 1-6 (2013).

38. Zooker, C., Pandarinath, R., Kraeutler, M. J., Ciccotti, M. G., Cohen, S. B. & Deluca, P. F. Clinical measurement of patellar tendon: accuracy and relationship to surgical tendon dimensions. *Am. J. Orthop.* **42,** 317-320 (2013).

39. Reider, B., Marshall, J. L., Koslin, B., Ring, B. & Girgis, F. G. The anterior aspect of the knee joint. *J. Bone Joint Surg. Am.* **63,** 351-356 (1981).

40. Farahmand, F., Sejiavongse, W. & Amis, A. A. Quantitative Study of the Quadriceps Muscles and Trochlear Groove Geometry Related to Instability of the Patellofemoral Joint. *J. Orthop. Res.* **16,** 136-143 (1998).

41. Baldwin, J. L. & House, C. K. Anatomic Dimensions of the Patella Measured During Total Knee Arthroplasty. *J. Arthroplasty* **20,** 250-257 (2005).

42. Wibeeg, G. Roentgenographs and anatomic studies on the femoropatellar joint: with special reference to chondromalacia patellae. *Acta Orthop. Scand.* **12,** 319-410 (1941).

43. Fucentese, S. F., von Roll, A., Koch, P. P., Epari, D. R., Fuchs, B. & Schottle, P. B. The patella morphology in trochlear dysplasia--a comparative MRI study. *Knee* **13,** 145-150 (2006).

44. Koyuncu, E., Cankara, N., Sulak, O., Özgüner, G. & Albay, S. The morphometry of patella and patellar ligament during the fetal period. *Clin. Anat.* **24,** 225-31 (2011).

45. Dos Santos Netto, A., de Brito, M.B.S., Severino, F.R., Campos, L.R.A., Nico, M.A.C., de Oliveira, V.M. & Severino, N.R. Study on the patellofemoral joint using magnetic resonance imaging : morphological variation of the medial patellofemoral ligament. *Rev. Bras. Ortop.* **47,** 204-209 (2012).

46. Higuchi, T., Arai, Y., Takamiya, H., Miyamoto, T., Tokunaga, D. & Kubo, T. An analysis of the medial patellofemoral ligament length change pattern using open-MRI. *Knee Surg. Sports Traumatol. Arthrosc.* **18,** 1470-1475 (2010).

47. Williams, W. R. Anatomy of the Knee Joint. *J. Anat. Physiol.* **14,** 178-184 (1880).

48. Tenney, B. I. The Anatomy and Surgery of the Internal Derangements of the Knee-Joint. Based on a Study of 150 Dissected Joints and the Literature. *Ann. Surg.* **40,** 1-34 (1904).

49. Tuxøe, J., Teir, M., Winge, S. & Nielsen, P. The medial patellofemoral ligament: a dissection study. *Knee Surg. Sports Traumatol. Arthrosc.* **10,** 138-140 (2002).

50. Smirk, C. & Morris, H. The anatomy and reconstruction of the medial patellofemoral ligament. *Knee* **10,** 221-227 (2003).

51. Viste, A., Chatelet, F., Desmarchelier, R. & Fessy, M. H. Anatomical study of the medial patello-femoral ligament: landmarks for its surgical reconstruction. *Surg. Radiol. Anat.* **36,** 733-739 (2014).

52. Aragão, J. A., Reis, F. P., Vasconcelos, D. P.D., Feitosa, V. L. C. & Nunes, M. A. P. Metric measurements and attachment levels of the medial patellofemoral ligament: an anatomical study in cadavers. *Clinics* **63,** 541-544 (2008).

53. Nomura, E., Inoue, M. & Osada, N. Anatomical analysis of the medial patellofemoral ligament of the knee, especially the femoral attachment. *Knee Surg. Sports Traumatol. Arthrosc.* **13,** 510-515 (2005).

54. Mochizuki, T., Nimura, A., Tateishi, T., Yamaguchi, K., Muneta, T. & Akita, K. Anatomic study of the attachment of the medial patellofemoral ligament and its characteristic relationships to the vastus intermedius. *Knee Surg. Sports Traumatol. Arthrosc.* **21,** 305-310 (2013).

55. Placella, G., Tei, M. M., Sebastiani, E. G., Criscenti, A., Speziali, C., Mazzola, A., Georgoulis, A. & Cerulli., G. Shape and size of the medial patellofemoral ligament for the best surgical reconstruction : a human cadaveric study. *Knee Surg. Sports Traumatol. Arthrosc.* **22,** 2327-2333 (2014).

56. Steensen, R. N., Dopirak, R. M. & McDonald, W. G. The anatomy and isometry of the medial patellofemoral ligament: implications for reconstruction. *Am. J. Sports Med.* **32,** 1509-1513 (2004).

57. Kang, H. J., Wang, F., Chen, B. C., Su, Y. L., Zhang, Z. C. & Yan, C. B. Functional bundles of the medial patellofemoral ligament. *Knee Surg. Sports Traumatol. Arthrosc.* **18,** 1511-1516 (2010).

58. Philippot, R., Chouteau, J., Wegrzyn, J., Testa, R., Fessy, M.H. & Moyen, B. Medial patellofemoral ligament anatomy: implications for its surgical reconstruction. *Knee Surg. Sports Traumatol. Arthrosc.* **17,** 475-479 (2009).

59. Kikuchi, S., Tajima, G., Yan, J., Kamei, Y., Maruyama, M., Sugawara, A., Fujino, K., Takeda, S. & Doita, M. Morphology of insertion sites on patellar side of medial patellofemoral ligament. *Knee Surg. Sports Traumatol. Arthrosc.* 1-6 (2016).

60. De Oliveira, V., De Souza, V., Cury, R., Camargo, O. P., Avanzi, O., Severino, N. & Fucs, P. Medial patellofemoral ligament anatomy: Is it a predisposing factor for lateral patellar dislocation? *Int. Orthop.* **38,** 1633-1639 (2014).

61. Senavongse, W. & Amis, A. A. The effects of articular, retinacular, or muscular deficiencies on patellofemoral joint stability. *Bone Joint J.* **87,** 577-582 (2005).

62. Pfirrmann, C. W., Zanetti, M., Romero, J. & Hodler, J. Femoral trochlear dysplasia: MR findings 1. *Radiology* **216,** 858-864 (2000).

63. Balcarek, P., Walde, T. A., Frosch, S., Schüttrumpf, J. P., Wachowski, M. M., Stürmer, K. M. & Frosch, K. H. Patellar dislocations in children, adolescents and adults: a comparative MRI study of medial patellofemoral ligament injury patterns and trochlear groove anatomy. *Eur. J. Radiol.* **79,** 415-420 (2011).

64. Balcarek, P., Jung, K., Ammon, J., Walde, T.A., Frosch, S., Schüttrumpf, J.P., Stürmer, K.M. & Frosch, K.H. Anatomy of lateral patellar instability: trochlear dysplasia and tibial tubercle-trochlear groove distance is more pronounced in women who dislocate the patella. *Am. J. Sports Med.* **38,** 2320-7 (2010).

65. Charles, M. D., Haloman, S., Chen, L., Ward, S. R., Fithian, D. & Afra, R. Magnetic Resonance Imaging-Based Topographical Differences Between Control and Recurrent Patellofemoral Instability Patients. *Am. J. Sports Med.* **41,** 374-384 (2013).

66. Wanner, J. A. Variations in the Anterior Patellar Groove of the Human Femur. *Am. J. Phys. Anthr.* **47,** 99-102 (1977).

67. Shih, Y. F., Bull, A. M. & Amis, A. A. The cartilaginous and osseous geometry of the femoral trochlear groove. *Knee Surg. Sports Traumatol. Arthrosc.* **12,** 300-306 (2004).

68. Glard, Y.,Jouve, J.L., Garron, E., Adalian, P., Tardieu, C. & Bollini, G. Anatomic study of femoral patellar groove in fetus. *J. Pediatr. Orthop.* **25,** 305-308 (2005).

69. Diederichs, G., Issever, A. S. & Scheffler, S. MR Imaging of Patellar Instability : Injury Patterns and Assessment of Risk. *Radiographics* **30,** 961-981 (2010).

70. Bollier, M. & Fulkerson, J. P. The role of trochlear dysplasia in patellofemoral instability. *J. Am. Acad. Orthop. Surg.* **19,** 8-16 (2011).

71. Stensdotter, A.K., Andersson, P.I., Rydh, A. & Häger-Ross, C. Q-angle variations in standing and supine positions and for different measurement methods in women with and without patellofemoral pain. *Adv. Physiother.* **11,** 88-96 (2009).

72. Schneider, C. A., Rasband, W. S. & Eliceiri, K. W. NIH Image to ImageJ: 25 years of image analysis. *Nat. Methods* **9,** 671-675 (2012).

73. McDonald, J. H. *Handbook of biological statistics*. (Sparky House Publishing, 2009).

74. Zar, J. H. *Biostatistical Analysis*. (Prentice Hall USA, 1984).

75. LaPrade, R. F., Engebretsen, A. H., Ly, T. V., Johansen, S., Wentorf, F. A. & Engebretsen, L. The anatomy of the medial part of the knee. *J. Bone Joint Surg. Am.* **89,** 2000-2010 (2007).

76. Philippot, R., Boyer, B., Testa, R., Farizon, F. & Moyen, B. The role of the medial ligamentous structures on patellar tracking during knee flexion. *Knee Surg. Sports Traumatol. Arthrosc.* **20,** 331-336 (2012).

77. Kohn, L.M., Meidinger, G., Beitzel, K., Banke, I.J., Hensler, D., Imhoff, A.B. & Schöttle, P.B. Isolated and combined medial patellofemoral ligament reconstruction in revision surgery for patellofemoral instability: a prospective study. *Am. J. Sports Med.* **41,** 2128-35 (2013).

78. Matsushita, T., Kuroda, R., Araki, D., Kubo, S., Matsumoto, T. & Kurosaka, M. Medial patellofemoral ligament reconstruction with lateral soft tissue release in adult patients with habitual patellar dislocation. *Knee Surg. Sports Traumatol. Arthrosc.* **21,** 726-30 (2013).

79. Shafizadeh, S. & Balke, M. Medial Patellofemoral Ligament Reconstruction: A New Technique for Graft Fixation at the Patella Without Implants. *Arthrosc. Tech.* **3,** e115-e117 (2014).

80. Schöttle, P., Schmeling, A., Romero, J. & Weiler, A. Anatomical reconstruction of the medial patellofemoral ligament using a free gracilis autograft. *Arch. Orthop. Trauma Surg.* **129,** 305-309 (2009).

Appendix A: Ethical approval to complete the study. Ethical number ECUFS138/2015

UNIVERSITY OF THE FREE STATE
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HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

IRB nr 00006240
REC Reference nr 230408-011
IORG0005187
FWA00012784

12 August 2015

MR WJ HENNING
DEPARTMENT OF BASIC MEDICAL SCIENCES
FACULTY OF HEALTH SCIENCES
UFS

Dear Mr WJ Henning

ECUFS 138/2015 **DEPARTMENT OF BASIC MEDICAL SCIENCES**
PROJECT TITLE: THE CORRELATION OF THE MORPHOLOGY OF THE MEDIAL PATELLOFEMORAL LIGAMENT (MPFL) WITH THE DIMENSIONS OF THE PATELLA, THE PATELLAR TENDON, THE Q-ANGLE AND FEMORAL TROCHLEAR GROOVE

1. You are hereby kindly informed that, at the meeting held on 11 August 2015, the Ethics Committee approved the above project.

2. Any amendment, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

3. A progress report should be submitted within one year of approval of long term studies and a final report at completion of both short term and long term studies.

4. Kindly use the ECUFS NR as reference in correspondence to the Ethics Committee Secretariat.

5. The Ethics Committee functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the Ethics Committee of the Faculty of Health Sciences.

Yours faithfully

....
DR SM LE GRANGE
CHAIR: ETHICS COMMITTEE

Cc: Dr HJ Geyer

Ethics Committee
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Appendix B: The measurement data of the Q-angle, the patellar tendon, the patella, the MPFL and the femoral trochlear groove

Number	Year	Gender	Knee	Age	Q-Angle	MPFLL	MPFLP	MPFLF	MPFLM	MPFLVI
1	2014	female	L	80	12	58.97	41.18	11.33	26.37	18.02
1	2014	female	R	80	9	58.14	42.25	11.43	22.8	26.83
2	2014	female	L	77	12.5	63.16	44.64	14.88	18.45	28.8
2	2014	female	R	77	6	65.16	43.83	13.54	21.44	31.25
4	2014	female	L	34	11	66.51	54.57	9.68	24.53	26.77
4	2014	female	R	34	10.5	65.44	51.19	11.46	27.61	28.21
9	2014	male	L	31	6.5	68.89	50.15	13.81	26.62	24.44
9	2014	male	R	31	6.5	69.65	49.64	13.88	22.86	23.6
10	2014	male	L	41	12.5	65.99	51.19	14.86	25.24	22.72
10	2014	male	R	41	7	69.98	54.34	12.8	21.59	24.76
12	2014	female	L	52	8	60.71	55.01	12.69	20.76	29.83
12	2014	female	R	52	11.5	59.8	53.76	15.81	29.7	24.49
14	2013	male	L	82	11.5	68.9	48.85	15.62	19.17	23.26
14	2013	male	R	82	12.5	67.11	49.29	13.61	19.71	21.98
21	2014	male	L	50	1.5	77.03	66.5	11.71	25.85	35.42
21	2014	male	R	50	2			No MPFL		
22	2014	male	L	69	15	73.46	50.62	18.87	31.09	30.61
22	2014	male	R	69	11	75.75	51.1	16.95	28.21	29.49
23	2014	male	L	48	8	67.67	44.04	15.67	22.24	23.17
23	2014	male	R	48	7.5	64.94	45.17	16.2	23.22	22.13
26	2014	male	L	74	11.5	75.33	50.56	14.33	20.87	22.21
26	2014	male	R	74	12	73.25	50.25	13.34	24.1	23.22
28	2014	female	L	87	15	54.27	46.88	14.66	22.46	21.74
28	2014	female	R	87	13	56.97	45.54	14.51	22.06	22.95
33	2014	male	L	82	13.5	67.13	52.24	13.81	26.44	23.66
33	2014	male	R	82	15	65.99	54.1	15.76	28.51	25.99
34	2014	male	L	52	16.5	71.52	52.6	14.74	34.96	22.24
34	2014	male	R	52	15.5	71.21	53.06	15.63	30.63	26.13
35	2014	female	L	49	12	74.38	46.27	7.59	13.52	24.65
35	2014	female	R	49	11	72.56	47.36	9.3	15.4	25.5
37	2014	male	L	49	15	72.45	49.24	18.7	22.83	22.5
37	2014	male	R	49	10	70.44	52.82	19.31	23.86	33.43
62	2014	female	L	77	4	69.01	48.17	23.65	23.46	28.28
62	2014	female	R	77	5	66.72	47.7	25.26	26.19	28.31

Number	Year	Gender	Knee	Age	OWP	OLP	ASHP	MFWP	LFWP	PTL	PPTW	DPTW
1	2014	female	L	80	39.6	38.83	29.63	20.24	23.54	36.57	20.34	27.31
1	2014	female	R	80	38.78	39.24	28.66	20.78	22.34	36.34	19.94	26.48
2	2014	female	L	77	42.74	39.1	32.25	19.68	28.03	49.73	21.35	28.24
2	2014	female	R	77	41.74	38.98	31.52	20.94	27.3	49.89	21.4	27.8
4	2014	female	L	34	40.95	37.71	32.45	22.01	24.66	50.14	23.65	24.39
4	2014	female	R	34	40.8	36.5	33.01	21.78	22.94	48.68	25.16	25.45
9	2014	male	L	31	47.87	46.85	36.24	25.3	29.3	49.78	24.7	33.04
9	2014	male	R	31	48.88	47.44	36.52	25.27	29.64	50.7	26.65	34.05
10	2014	male	L	41	41.35	42.05	30.28	24.55	25.91	45.46	27.4	35.54
10	2014	male	R	41	42.39	43.87	29.08	26.06	24.93	46.24	28.7	32.7
12	2014	female	L	52	40.14	36.27	29.24	19.53	22.43	34.94	23.08	25.59
12	2014	female	R	52	38.46	39.74	30.7	20.24	21.95	35.08	23.99	26.69
14	2013	male	L	82	47.11	44.83	31.84	25.44	26.87	47.76	25.69	32.85
14	2013	male	R	82	47.15	43.82	31.77	26.17	25.94	45.61	23.5	30.73
21	2014	male	L	50	43.08	39.96	33.98	19.68	27.02	51.41	22.58	29.45
21	2014	male	R	50				No MPFL				
22	2014	male	L	69	52.75	50.21	39.14	30.27	31.19	52.79	28.42	35.24
22	2014	male	R	69	52.95	51.66	39.44	28.66	29.91	52.97	27.26	36.49
23	2014	male	L	48	45.35	45.57	33.44	22.85	28.12	42.62	29.38	31.07
23	2014	male	R	48	46.76	45.41	34.35	22.54	29.74	41.52	28.41	32.68
26	2014	male	L	74	49.4	43.8	34.04	25.75	30.17	47	25.82	32.96
26	2014	male	R	74	50.34	45.65	32.81	25.46	29.04	46.84	25.33	32.91
28	2014	female	L	87	45.06	40.03	31.74	22.26	28.48	44.28	21.88	30.06
28	2014	female	R	87	46.49	40.73	31.33	23.07	28.18	44.24	23.24	29.69
33	2014	male	L	82	44.92	40.17	32.05	23.94	30.49	43.23	22.03	28.82
33	2014	male	R	82	45.56	40.99	32.39	22.51	28.78	43.19	22.77	27.68
34	2014	male	L	52	46.56	46.52	33.71	26.9	28.37	39.17	23.78	29.3
34	2014	male	R	52	45.41	45.33	33.99	26.23	27.84	40.02	23.46	30.14
35	2014	female	L	49	38.95	40.5	34.06	24.01	25.78	48.02	20.81	28
35	2014	female	R	49	38.11	39.94	34.39	22.71	24.97	47.81	21.13	27.37
37	2014	male	L	49	47.58	50.31	36.87	25.15	28.22	49.34	26.06	31.76
37	2014	male	R	49	48.43	49.01	38.34	24.44	28.27	48.71	26.25	32.38
62	2014	female	L	77	42.25	42.92	33.59	19.07	24.16	51.89	25.33	31.22
62	2014	female	R	77	42.44	42.99	33.73	20.22	24.31	50.9	24.68	29.69

Number	Year	Gender	Knee	Age	MFGW	LFGW	AMM	ALM	ADP	α	DFTG	TGA
1	2014	female	L	80	8.47	12.76	56.06	57.48	54.71	156.29	2.06	0.663793
1	2014	female	R	80	8.8	14.15	57.25	57.97	55.45	155.17	2.16	0.621908
2	2014	female	L	77	11.36	16.75	59.44	60.38	56.09	147.55	3.82	0.678209
2	2014	female	R	77	11.95	16.16	60.43	60.55	56.69	148.22	3.8	0.73948
4	2014	female	L	34	10.41	16.93	53.96	57.47	51.87	148.18	3.85	0.614885
4	2014	female	R	34	10.65	15.71	55.12	55.47	51.3	148.24	4	0.677912
9	2014	male	L	31	13.73	20.78	62.91	67.25	59.32	143.88	5.76	0.660731
9	2014	male	R	31	13.1	23.01	64.54	68.15	60.66	144.97	5.69	0.569318
10	2014	male	L	41	13.58	19.02	61.14	67.52	58.74	140.05	5.59	0.713985
10	2014	male	R	41	12.69	17.55	61.21	67.19	59.22	142.71	4.97	0.723077
12	2014	female	L	52	9.37	14.39	50.29	52.33	48.74	156.36	2.57	0.651147
12	2014	female	R	52	8.9	17.03	50.75	52.26	48.86	155.13	2.65	0.522607
14	2013	male	L	82	11.7	20.54	61.25	65.29	57.32	137.15	5.95	0.56962
14	2013	male	R	82	13.05	20.01	62.05	64.27	56.88	134.85	6.28	0.652174
21	2014	male	L	50	12.2	17.73	58.84	61.54	56.22	149.22	3.97	0.688099
21	2014	male	R	50				No MPFL				
22	2014	male	L	69	15.09	21.05	67.88	71.25	64.15	146.24	5.41	0.716865
22	2014	male	R	69	14.68	21.99	67.82	70.73	64.07	146.13	5.21	0.667576
23	2014	male	L	48	13.45	19.01	59.83	62.32	55.88	142.83	5.2	0.707522
23	2014	male	R	48	13.03	21.35	60.91	63.21	56.94	143.31	5.12	0.610304
26	2014	male	L	74	14.01	20.74	64.94	64.94	58.48	137.76	6.46	0.675506
26	2014	male	R	74	13.95	22.45	65.23	64.4	58.58	136.86	6.24	0.621381
28	2014	female	L	87	10.33	14.82	57.6	57.74	54.76	152.78	2.91	0.697031
28	2014	female	R	87	10.71	16.02	57.15	58.5	54.57	146.87	3.26	0.668539
33	2014	male	L	82	13	19.7	58.49	61.62	55.47	147.03	4.59	0.659898
33	2014	male	R	82	12.14	20.07	59.39	59.64	55.62	148.7	3.9	0.604883
34	2014	male	L	52	13.23	18.39	60.64	64.84	57.61	143.85	5.13	0.719413
34	2014	male	R	52	13.17	19.1	61.84	62.64	57.23	140.93	5.01	0.689529
35	2014	female	L	49	12.2	16.85	54.98	58.62	51.58	139	5.22	0.724036
35	2014	female	R	49	11.11	17.12	56.13	58.22	52.26	143.44	4.92	0.648949
37	2014	male	L	49	12.65	17.18	66.55	68.52	64.38	158.58	3.16	0.736321
37	2014	male	R	49	13.35	17.7	67.8	69.17	65.08	155.37	3.41	0.754237
62	2014	female	L	77	12.65	18.31	60.95	64.17	58.11	148.85	4.45	0.690879
62	2014	female	R	77	8.66	23.57	61.68	64.07	59.46	152.65	3.42	0.367416

Appendix C: Determining the critical value of the Spearman's correlation coefficient for a sample size of n=33 with two degrees of freedom

Critical Values of the Spearman's Ranked Correlation Coefficient

Taken from Zar, 1984 Table B.19

α(2):	0.50	0.20	0.10	0.05	0.02	0.01	0.005	0.002	0.001
α(1):	0.25	0.10	0.05	0.025	0.01	0.005	0.0025	0.001	0.0005
n									
4	0.600	1.000	1.000						
5	0.500	0.800	0.900	1.000	1.000				
6	0.371	0.657	0.829	0.886	0.943	1.000	1.000		
7	0.321	0.571	0.714	0.786	0.893	0.929	0.964	1.000	1.000
8	0.310	0.524	0.643	0.738	0.833	0.881	0.905	0.952	0.976
9	0.267	0.483	0.600	0.700	0.783	0.833	0.867	0.917	0.933
10	0.248	0.455	0.564	0.648	0.745	0.794	0.830	0.879	0.903
11	0.236	0.427	0.536	0.618	0.709	0.755	0.800	0.845	0.873
12	0.217	0.406	0.503	0.587	0.678	0.727	0.769	0.818	0.846
13	0.209	0.385	0.484	0.560	0.648	0.703	0.747	0.791	0.824
14	0.200	0.367	0.464	0.538	0.626	0.679	0.723	0.771	0.802
15	0.189	0.354	0.446	0.521	0.604	0.654	0.700	0.750	0.779
16	0.182	0.341	0.429	0.503	0.582	0.635	0.679	0.729	0.762
17	0.176	0.328	0.414	0.485	0.566	0.615	0.662	0.713	0.748
18	0.170	0.317	0.401	0.472	0.550	0.600	0.643	0.695	0.728
19	0.165	0.309	0.391	0.460	0.535	0.584	0.628	0.677	0.712
20	0.161	0.299	0.380	0.447	0.520	0.570	0.612	0.662	0.696
21	0.156	0.292	0.370	0.435	0.508	0.556	0.599	0.648	0.681
22	0.152	0.284	0.361	0.425	0.496	0.544	0.586	0.634	0.667
23	0.148	0.278	0.353	0.415	0.486	0.532	0.573	0.622	0.654
24	0.144	0.271	0.344	0.406	0.476	0.521	0.562	0.610	0.642
25	0.142	0.265	0.337	0.398	0.466	0.511	0.551	0.598	0.630
26	0.138	0.259	0.331	0.390	0.457	0.501	0.541	0.587	0.619
27	0.136	0.255	0.324	0.382	0.448	0.491	0.531	0.577	0.608
28	0.133	0.250	0.317	0.375	0.440	0.483	0.522	0.567	0.598
29	0.130	0.245	0.312	0.368	0.433	0.475	0.513	0.558	0.589
30	0.128	0.240	0.306	0.362	0.425	0.467	0.504	0.549	0.580
31	0.126	0.236	0.301	0.356	0.418	0.459	0.496	0.541	0.571
32	0.124	0.232	0.296	0.350	0.412	0.452	0.489	0.533	0.563
33	0.121	0.229	0.291	0.345	0.405	0.446	0.482	0.525	0.554
34	0.120	0.225	0.287	0.340	0.399	0.439	0.475	0.517	0.547
35	0.118	0.222	0.283	0.335	0.394	0.433	0.468	0.510	0.539
36	0.116	0.219	0.279	0.330	0.388	0.427	0.462	0.504	0.533
37	0.114	0.216	0.275	0.325	0.383	0.421	0.456	0.497	0.526
38	0.113	0.212	0.271	0.321	0.378	0.415	0.450	0.491	0.519
39	0.111	0.210	0.267	0.317	0.373	0.410	0.444	0.485	0.513
40	0.110	0.207	0.264	0.313	0.368	0.405	0.439	0.479	0.507
41	0.108	0.204	0.261	0.309	0.364	0.400	0.433	0.473	0.501
42	0.107	0.202	0.257	0.305	0.359	0.395	0.428	0.468	0.495
43	0.105	0.199	0.254	0.301	0.355	0.391	0.423	0.463	0.490
44	0.104	0.197	0.251	0.298	0.351	0.386	0.419	0.458	0.484
45	0.103	0.194	0.248	0.294	0.347	0.382	0.414	0.453	0.479
46	0.102	0.192	0.246	0.291	0.343	0.378	0.410	0.448	0.474
47	0.101	0.190	0.243	0.288	0.340	0.374	0.405	0.443	0.469
48	0.100	0.188	0.240	0.285	0.336	0.370	0.401	0.439	0.465
49	0.098	0.186	0.238	0.282	0.333	0.366	0.397	0.434	0.460
50	0.097	0.184	0.235	0.279	0.329	0.363	0.393	0.430	0.456