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The relationship between the angle of the trochlear groove and patella cartilage and bone morphology – a cross-sectional study of healthy adults

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Summary

Objectives: Although the geometry of the trochlear groove is considered important in the pathogenesis of patellofemoral joint pathology it is unclear how the shape of the trochlear groove relates to patella morphology. This cross-sectional study investigated the relationship between the shape of the trochlear groove and patella cartilage and bone morphology in healthy adults.

Methods: Two hundred and ninety-seven healthy adults aged between 50 and 79 years with no clinical history of knee pain or pathology were examined using magnetic resonance imaging (MRI). From the magnetic resonance (MR) images, the bony angles formed at the distal and proximal trochlear groove were measured, together with patella cartilage and bone volumes and patella cartilage defects.

Results: After adjustment for potential confounders, there was an 8.70 mm^3 (95% confidence interval (CI) 2.15, 15.26) increase in patella cartilage volume ($P = 0.009$), with no increased prevalence of cartilage defects (odds ratio = 0.99 (95% CI 0.96, 1.02), $P = 0.35$), for every 1° increase (i.e., as the angle became more flatter) at the distal trochlear groove. Moreover, there was a 53.86 mm^3 (95% CI −90.26, −17.46) reduction in patella bone volume for every 1° that the angle at the distal trochlear groove became more flattened ($P = 0.004$). No significant association between the proximal trochlear groove angle and the patella cartilage or bone properties was observed.

Conclusion: A more flattened bony angle at the distal trochlear groove was associated with increased patella cartilage volume and reduced patella bone volume, but no increased prevalence of patella cartilage defects in adults with no history of knee pain or clinical disease. These cross-sectional findings suggest that a flattened distal trochlear groove may protect against degenerative patellofemoral conditions, such as osteoarthritis, but this will need to be confirmed in a longitudinal study.

Key words: Knee, Cartilage, Patella, Trochlear, Sulcus, Bone.

Introduction

The geometry of an articular surface is an important determinant of joint function. For instance, incongruent joints often sacrifice stability for mobility and as a result, are prone to pathological processes. The patellofemoral joint is one example of an incongruent articulation[1] commonly affected by painful conditions, including patellofemoral pain syndrome, instability and osteoarthritis[2–6]. Despite the high prevalence and frequent disability that accompanies knee pain associated with patellofemoral pathology[7], epidemiological studies have predominantly focussed on the tibiofemoral compartment of the knee.

The patellofemoral joint is formed by the articulation between the irregularly shaped patella and the trochlear groove, which is located between the distal femoral condyles. The articulation and contact patterns between the patella and trochlear groove change throughout knee range of movement, with greatest stability being provided beyond 45° of knee flexion, where the patella moves inferiorly to be completely engaged with the trochlear groove. Whereas retropatellar load is theoretically greatest when the patella is articulating with the distal trochlear groove during knee flexion, compressive forces are reduced and the patellofemoral joint is subject to less stability as the knee extends and the patella makes irregular contact with the proximal trochlear groove[6]. Despite this anatomical and functional relationship, there are a paucity of studies that have examined

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the association between different landmarks along the trochlear groove and patella structure.

Of the landmarks along the trochlear groove, the femoral sulcus angle, which is thought to represent the deepest depression of the trochlear groove relative to the femoral condyles, has received some attention[2,4]. While the femoral sulcus angle is commonly assessed via the skyline view from knee joint radiographs, the view provides a two-dimensional assessment of a three-dimensional structure, and is dependant upon the degree of knee flexion to provide reliable data. Moreover, the skyline view is unable to differentiate between the distal and proximal trochlear groove, and may, therefore, not provide the most valid and reliable assessment of trochlear groove depth. Of the few non-radiographic studies of the distal femur, a recent magnetic resonance imaging (MRI) study demonstrated that people with patellar instability have a flatter distal trochlear groove than pain-free people[4]. Nevertheless, it is not clear whether the trochlear groove is associated with the properties of patella cartilage, particularly in the absence of patellofemoral disease.

The aim of this cross-sectional study was to determine the relationships between patella cartilage and bone and the distal and proximal angles of the trochlear groove in a group of healthy adults undergoing MRI.

Methods

SUBJECTS

Subjects were recruited from the Melbourne Collaborative Cohort Study (MCCS), which is a prospective cohort study of community-based people, aged 40–69 years, that is examining the role of lifestyle and genetic factors in the risk of cancer and chronic diseases from middle age and beyond, as previously described[8]. As our intent was to investigate subjects with no clinical osteoarthritis, as defined by the American College of Rheumatology clinical criteria[9], as well as no significant current or past knee disease, individuals were excluded if in the last 5 years they had knee pain lasting for >24 h; a previous knee injury requiring non-weight bearing treatment for >24 h or surgery (including arthroscopy); or a history of any arthritis diagnosed by a medical practitioner. A further exclusion criterion was a contraindication to MRI, as previously described[10]. We invited subjects, who fulfilled our inclusion criteria and had attended the first year of round 3 follow-up of the MCCS which commenced in 2003, to participate in the current study. We used quota sampling whereby recruitment ceased when our target sample of approximately 300 subjects was achieved. The study was approved by the Human Research Ethics Committee of The Cancer Council of Victoria and Monash University Standing Committee on Ethics in Research Involving Humans. All participants gave written informed consent.

DATA COLLECTION

Study participants completed a questionnaire that included information on their demographics and past medical and surgical history. Weight was measured to the nearest 0.1 kg (shoes, socks, and bulky clothing removed) using a single pair of electronic scales. Height was measured to the nearest 0.1 cm (shoes and socks removed) using a stadiometer. From these data, body mass index (BMI) (kg m^{-2}) was calculated.

MAGNETIC RESONANCE IMAGING

MRI was performed on the dominant knee (defined as the lower limb the subject used to step-off with when initiating walking) of each participant. Knees were imaged in full extension in the sagittal plane on a 1.5-T whole body magnetic resonance (MR) unit (Phillips) using a commercial transmit-receive extremity coil. The following sequence parameters were used: a T1-weighted fat suppressed 3D gradient recall acquisition in the steady state; flip angle 55°; repetition time 58 ms; echo time 12 ms; field of view 16 cm; 60 partitions; 513 × 196 matrix; one acquisition time 11 min 56 s. Sagittal images were obtained at a partition thickness of 1.5 mm and an in-plate resolution of 0.31 × 0.83 mm (512 × 196 pixels).

Trochlear groove angle

MR images were reformatted in the axial plane to enable the trochlear groove angles to be directly measured from these images on an independent workstation using the software program Osiris (University of Geneva). The bony angles were measured at defined levels at the distal and proximal aspects of the trochlear groove. The distal trochlear groove angle was measured from the most inferior slice imaging through the trochlear groove that is immediately prior to the level at which the medial and lateral condyles separate [see Fig. 1(a)]. The proximal trochlear groove angle was measured at the most superior slice where the femoral cartilage could be clearly defined on the anterior surface of the femur [see Fig. 1(b)]. Coefficients of variation for the distal and proximal angles were 6.1% and 4.4%, respectively.

Cartilage and bony properties

Patella cartilage and bone volumes were determined by image processing using the Osiris software as previously described[11]. Contours were drawn around the patella in images 1.5 mm apart on sagittal views. The coefficients of variation were 2.1% for patella cartilage volume and 2.2% for patella bone volume[11].

Cartilage defects at the patellofemoral site were graded by a trained observer from the MR images using a modified classification system[12]. A cartilage defect was characterised by irregularity on either the articular surface or the cartilage base associated with loss of cartilage thickness of at least 50%. For a defect to be present, it had to be identifiable on at least two consecutive slices. The same trained observer, as well as an independent observer, re-graded the cartilage defects 1 month later blinded to the previous assessment. Intra-observer and inter-observer reliability for the patellar compartment (expressed as an intra-class correlation) were 0.94 and 0.93, respectively[13].

STATISTICAL ANALYSES

With a sample size of 297, this study was designed to have 80% power to detect a correlation as low as 0.15 between various risk factors and knee cartilage volume (alpha error 0.05, two sided significance), thus explaining up to 2.2% of the variance of cartilage volume.

Cartilage and bone volumes were initially assessed for normality before being regressed against the distal and proximal trochlear groove angles using linear regression. Logistic regression was used to determine the relationship between the presence of patella cartilage defects and the distal and proximal trochlear groove angles. Known

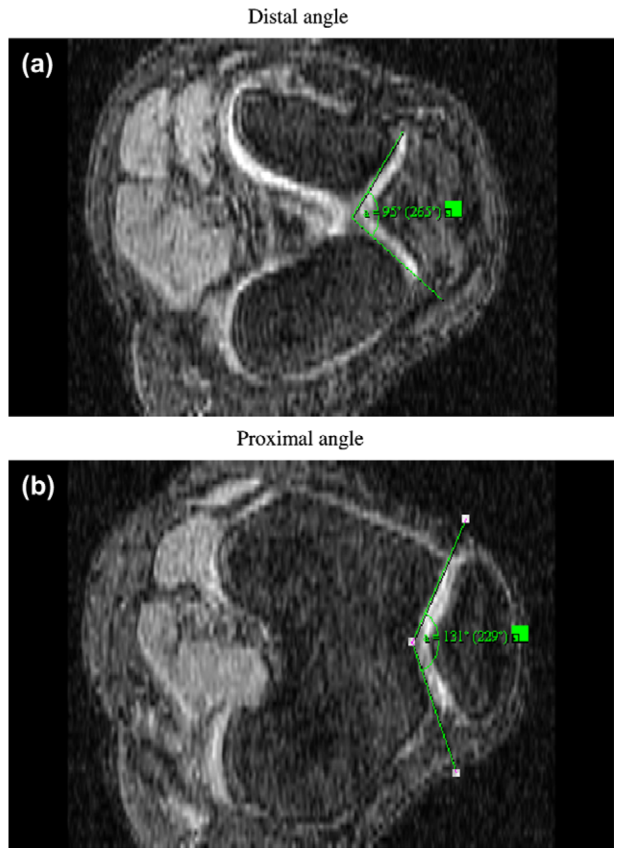

Fig. 1. Trochlear groove angles as measured by MRI. (a) The distal bony trochlear groove angle was measured from the most inferior slice imaging through the trochlear groove that is immediately prior to the level at which the medial and lateral condyles separate. (b) The proximal bony trochlear groove angle was measured at the most superior slice where the femoral cartilage could be clearly defined on the anterior surface of the femur.

confounders including age, gender and BMI were adjusted for in both linear and logistic multivariate regression analyses. All analyses were performed using the SPSS statistical package (standard version 14.0, SPSS, Chicago, IL). A P value of less than 0.05 was considered to be statistically significant.

Results

The characteristics of the 297 subjects are shown in Table I. Their mean age was 58 (±5.5) years, while the mean BMI was 25.9 (±4.2) kg m^{-2}.

For every degree increase in the bony trochlear groove angle at the distal femur, there was an 8.70 mm^3 (95% confidence interval (CI) 2.15, 15.26) increase in patella cartilage volume ($P = 0.009$), without an increased prevalence of the presence of patella cartilage defects, after adjustment for potential confounders (Table II). Moreover, for every degree increase in the trochlear groove angle at the distal femur, there was a 53.86 mm^3 (95% CI −90.26, −17.47) reduction in the patella bone volume ($P = 0.004$) after adjustment for potential confounders (Table II). The angle formed at the proximal trochlear groove was not significantly associated with either patella cartilage or bone volume (Table II).

Table I
Characteristics of study subjects

	Total ($n = 297$)	Range
Gender (% female)	63	–
Age (years)	58 (5.5)	50–79
Height (cm)	168.1 (9.0)	148–194
Weight (kg)	73.2 (14.0)	41–123
BMI (kg m^{-2})	25.9 (4.2)	17.5–41.5
Trochlear groove angle (degrees)		
Distal	103 (9.8)	78–135
Proximal	147 (8.3)	119–166
Patella cartilage volume (mm^2)	2656 (886)	407–5682
Presence of patella cartilage defects	83 (28%)	–
Patella bone volume (mm^3)	20,276 (4667)	8180–35,700

Values are reported as mean (±SD) at baseline unless otherwise stated.

Discussion

We have demonstrated that as the distal femoral trochlear groove becomes more flattened, there is an associated increase in patella cartilage volume without an increased prevalence of patella cartilage defects among healthy adults with no history of knee pain or clinical disease. Additionally, a more flattened distal trochlear groove was associated with a reduction in patella bone volume. These cross-sectional findings suggest that a flattened distal trochlear groove may protect against degenerative patellofemoral conditions, such as osteoarthritis, but this will need to be confirmed in a longitudinal study.

No previous study has examined the relationship between the trochlear groove and patella cartilage in people with or without knee pathology. We have demonstrated that a more flattened distal trochlear groove was associated with increased patella cartilage volume, without the risk of cartilage defects. Reduced cartilage volume is a recognised feature of patellofemoral osteoarthritis and cartilage defects are thought to represent early arthritic change and have been shown to predate localised cartilage loss and disease progression[10]. Further, this study demonstrated that a more flattened distal trochlear groove was associated with reduced patella bone volume. Similarly, a recent study demonstrated that the patella was smaller in people with pathologically flattened distal trochlear grooves than in normal controls[14]. Although bony enlargement is a feature of tibiofemoral osteoarthritis[15], it is uncertain whether increased patella bone volume is a feature of patellofemoral osteoarthritis.

On the other hand, we did not demonstrate any significant association between the proximal trochlear groove angle and either patella cartilage or bone. Biomechanically, the patella tracks distally with increasing degrees of knee flexion, which enhances patellofemoral stability as the retropatellar load increases[6]. A recent MRI study validated that patellofemoral contact area was larger with increasing degrees of knee flexion[16]. Hence, the greatest contact area for articulation between the patella and femur occurs distally along the trochlear groove, which may help to explain the association between patella cartilage and bone volume and the distal trochlear groove we observed in this study. This may indicate that the proximal trochlear groove depth is a particularly important determinant of patellofemoral stability. We may not have observed any significant association between the angle formed at the proximal trochlear groove and patella cartilage or bone given that our subject selection is likely to have excluded people with patellofemoral instability.

Table II
The relationship between trochlear groove angles and cartilage and bony properties of the patella

	Univariate analyses (95% CI)†	*P* value	Multivariate analyses (95% CI)	*P* value
Proximal trochlear groove				
Cartilage volume (mm^3)	−5.20 (−17.44, 7.05)	0.40	2.16 (−5.44, 9.75)‡	0.58
Bone volume (mm^3)	−46.87 (−111.33, 17.58)	0.15	4.99 (−37.93, 47.92)§	0.82
Presence of cartilage defects*	1.00 (0.97, 1.03)	0.95	1.00 (0.95, 1.05)‖	0.99
Distal trochlear groove				
Cartilage volume (mm^3)	14.25 (3.98, 24.53)	0.01	8.70 (2.15, 15.26)‡	0.009
Bone volume (mm^3)	16.06 (−38.81, 70.92)	0.57	−53.86 (−90.26, −17.47)§	0.004
Presence of cartilage defects*	0.98 (0.95, 1.00)	0.08	0.99 (0.96, 1.02)‖	0.35

*Data displayed as odds ratios.

†Change in dependant variable per degree increase in the angle at the trochlear groove (i.e., as the groove becomes shallower).

‡Change patella cartilage volume (mm^3) per degree increase in the angle at the trochlear groove (i.e., as the groove becomes shallower) after adjustment for age, gender, BMI and patella bone volume (mm^3) in the regression equation.

§Change in patella bone volume (mm^3) per degree increase in the angle at the trochlear groove (i.e., as the groove becomes shallower) after adjustment for age, gender and BMI in the regression equation.

‖Odds ratio for the presence of cartilage defects per degree increase in the angle at the trochlear groove (i.e., as the groove becomes shallower) after adjustment for age, gender, BMI and patella cartilage volume (mm^3) in the regression equation.

How a flattened distal trochlear groove might be associated with increased patella cartilage volume and reduced patella bone volume is unclear. It is speculated that cartilage integrity is maintained by mechanical stimulation. Furthermore, it has been postulated that when load exceeds biological limits, cartilage integrity may be compromised[17]. Theoretically, a flattened groove increases the surface area for articulation at the patellofemoral joint. Increased contact area for articulation is believed to reduce contact pressure and thus allow better distribution of retropatellar joint load[18]. Therefore, a flattened rather than a deeper distal trochlear groove may be better suited to providing optimal mechanical stimulation to articular cartilage, without causing degenerative changes. Further, the potentially reduced contact pressure imparted by a flattened trochlear groove may reduce joint load and account for the reduced patella bone volume. In accordance with Wolff's law[19], an animal study has demonstrated that bone which is subject to repetitive mechanical load responds by enlarging[20]. Similarly, a cross-sectional *in vivo* human study inferred that bony enlargement may occur in response to mechanical load at the knee[21]. Whether there is a genetic component to the relationship between trochlear groove angles and the properties of patella cartilage and bone remains unknown.

A limitation of our study may be the method used to assess the trochlear groove. Few studies have examined the trochlear groove using MRI, and as such, no standard protocol has been established. We developed and defined a reproducible method of measuring the shape of the trochlear groove three-dimensionally. To our knowledge, the only other study to have examined the distal trochlear groove via MRI measured trochlear groove depth, rather than groove angle[4]. Also, our study examined healthy subjects aged between 50 and 79 years, and as such, our results cannot be generalised to people with existing knee pathology or in other age groups. Future studies examining people with established patellofemoral disease, and people of different ages are required. However, this study was strengthened by the exclusion of people with a past history of patellofemoral instability, given that they may have inherently biased the sample and demonstrated more flattened proximal trochlear grooves (e.g., via trochlear dysplasia). Nevertheless, while this study demonstrated that a flattened trochlear groove may hypothetically protect against degenerative changes in healthy adults, it must be acknowledged that too much flattening results in trochlear dysplasia. Moreover, although other anatomical features related to bony geometry, such as varus–valgus alignment and recurvatum, may have mediated our results, many of these factors are gender dependant. Since gender was controlled for in this study, our results are unlikely to have been influenced by many of the anatomical disparities that exist between men and women. Lifestyle factors, such as exercise type, intensity and frequency may however have influenced results. Finally, this was a cross-sectional study design and, future longitudinal examination is required to determine whether a flattened distal trochlear groove is protective against the onset of patellofemoral osteoarthritis.

This study is the first to demonstrate that a flattened bony trochlear groove at the distal femur is associated with increased patella cartilage volume and reduced patella bone volume among healthy adults without a history of knee pain or pathology. Our findings suggest that a flattened distal trochlear groove may reduce the risk for knee pathology, such as osteoarthritis, that is characterised by cartilage reduction and bony enlargement.

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