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Kinematic and dynamic axial computerized tomography of the normal patellofemoral joint

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Abstract. Fourteen normal volunteers with no history suggesting previous or current knee pathology underwent axial computed tomographic examination of the patellofemoral joint. There were 11 men and 3 women, whose ages ranged from 10 to 46 years (average 25 years). Axial images were obtained at 0°, 10°, 20°, 30°, 40°, and 60° flexion both with and without contraction of the thigh muscles. Thus, 12 images were obtained for each individual. The CT scanner was focused at the midpatellar level prior to each image. Three measurements were made on 24 knees for each individual: congruence angle (CA), patellar tilt angle (PTA), and sulcus angle (SA). PTA increased slightly from 0° to 20°, and decreased slightly with more flexion (not significant, NS). The lower limit of PTA was usually 9°–10°; it was not lower than 7° in any knee position. Muscle contraction increased PTA slightly at each degree of flexion (NS). Mean CA was +18.3° (SD 20.8°) at 0°, which means that normal individuals may have CAs as high as +39° at full extension. There was a gradual decrease in CAs with knee flexion. The mean values became negative between 20° and 60° flexion. Contraction of the thigh muscles caused lateralisation of the patella except at 30° and 40° flexion. This lateral pull was statistically significant at full extension ($P < 0.01$) and at 10° flexion ($P < 0.05$). The SA decreased gradually as the flexion of the knee increased. Angles at 0°, 10°, and 20° flexion were significantly higher than those at 40° and 60° flexion ($P < 0.05$). This study shows that CA, PTA and SA change depending on the degree of flexion of the knee, and that these angles show wide variations in the normal population. One should not rely on axial images taken at full extension, as this may erroneously lead to a diagnosis of subluxation in a normally tracking patella. The values obtained in this study may provide a basis for determining the type of patellar instability at different knee positions, and thus give a better profile or patellar tracking. This is a new concept. Besides, comparison of dynamic values obtained in this study with the ones in abnormal patellofemoral joints may also reveal useful information.

Key words: Patellofemoral joint – Computed tomography

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Introduction

Patellar tracking abnormalities are a major cause of anterior knee pain [6–8, 11]. Clinical diagnosis may be difficult because the signs and symptoms often mimic those of other forms of internal derangement of the knee [11]. Consequently, various radiographic techniques have been proposed, but the results of most of these procedures have been unsatisfactory [2–4, 16]. Furthermore, axial plain radiographic evaluation of the patellofemoral joint requires knee flexion of at least 25°–30°.

The above-mentioned factors, together with the recognition of the importance of evaluating patellar instability in the first 20°–30° of knee flexion, prompted the use of computed tomography (CT) and magnetic resonance imaging for investigating patellofemoral malalignment [8, 9, 14, 19, 21]. Utilizing these imaging modalities, the normal patellofemoral relationship has usually been studied during the first 30° of knee flexion. The study by Martinez et al. [13] was done at 0°, 20°, and 45° of knee flexion.

With the complexity of the patellofemoral relationship in mind, we hoped to gain more information by imaging the joint at a wider range of flexion. In addition, to simulate the condition during weight bearing and assess the influence of muscle contraction, we also obtained images with the thigh muscles contracted.

Materials and methods

Fourteen normal volunteers with no history suggesting previous or current knee pathology underwent axial CT examination of the patellofemoral joint. There were 11 men and 3 women, whose ages ranged from 10 to 46 years (average 25 years). CT images were obtained on a 5-s body scanner (Toshiba TCT-6005).

Simple wedges were used to place both knees at the desired angles of knee flexion, with the patient in the supine position. Axial images were obtained at 0°, 10°, 20°, 30°, 40° and 60° flexion. For each angle of knee flexion, images were obtained first without and then with voluntary isometric contraction of the quadriceps and hamstring muscles. The CT scanner was focused at the midpatellar level prior to taking each image. Thus, 12 images were obtained for each subject. In other words, measurements were made on 24 knees for each subject.

Three measurements were made from each image: (1) sulcus angle (SA), formed by the intersection of lines drawn parallel to the medial and lateral trochlear facets; (2) congruence angle (CA), obtained by bisecting the SA and then drawing a second line from the apex of the trochlea to the deepest portion of the median groove of the patella; and (3) patellar tilt angle (PTA), an angle subtended by a line parallel with the lateral patellar facet and the posterior condylar reference line.

The values were stored in a computer, and the mean values and standard deviations of the three angles were found for each knee position with and without muscle contraction.

The paired t-test was used to evaluate the effect of muscle contraction. Comparison of the three angles at various degrees of knee flexion was done by ANOVA. When a difference was noted, Tukey's procedure was used for multiple comparisons. A P-value below 0.05 was considered as statistically significant.

Results

The mean values and standard deviations of the three angles are shown in Table 1. PTA increased slightly during the first 20°, and decreased slightly with more flexion. These changes were not statistically significant (NS). Images taken with contraction followed the same pattern without significant changes. Muscle contraction increased PTA slightly at every degree of knee flexion (NS). The lower limit of normal rather than the upper limit is important for PTA. The lower limit was usually 9°–10°; it was not lower than 7° in any knee position.

Mean CA was +18.3° (SD 20.8.°) at full extension, which means that normal subjects may have CAs as high as +39°. CA was reduced to 4.8° ± 21.5° at 10° flexion. When compared to the value at full extension, this decrease almost reached significance. The mean values became increasingly negative between 20° and 60° flexion. The differences were nonsignificant in this range. CAs at 20°, 30°, 40°, and 60° flexion were significantly lower than the CA at full extension ($P < 0.05$). CA at 10° flexion was significantly higher than those at 40° and 60° flexion ($P < 0.05$).

Contraction of the thigh muscles caused lateralisation of the patella except at 30° and 40° flexion. This lateral pull was statistically significant at extension ($P < 0.01$) and at 10° flexion ($P < 0.05$). At 30° and 40° flexion, muscle contraction caused slight medialisation of the patella (NS). CAs with muscle contraction decreased with flexion similarly to what was seen without contraction (the static condition). When dynamic CAs were compared among themselves, CA at extension was significantly higher than those at 10°–60° flexion.

The SA decreased gradually as the flexion of the knee increased. When analysed successively, this decrease was not significant. On the other hand, SAs at 0°, 10°, and 20° flexion were significantly higher than those at 40° and 60° flexion. SA was significantly higher at 30° flexion than at 60° flexion ($P < 0.05$).

Discussion

Although various conventional radiographic techniques have been proposed to evaluate patellar malalignment, there has been general dissatisfaction with most of these procedures [12, 13, 18]. The problems have been technical and interpretational. Recently, it has been emphasised that patellar tracking abnormalities are more likely to be demonstrated during the early phases of flexion [2, 12, 13, 18, 19, 21].

After finding the normal values of the angles reported in this study, we studied a series of patients with anterior knee pain. This is the subject of another paper which is yet unpublished. In that study, we measured the patellar tilt angle, congruence angle and sulcus angle at 0°–40° and at 60° flexion separately, compared with normal values, and determined the type of abnormality at each knee position. Thus, a table demonstrating the types of patellar tracking abnormalities at various knee positions was obtained. This table clearly demonstrated the necessity of obtaining serial axial images of the patellofemoral joint. Another conclusion drawn from that study was that imaging only in the first 30° of knee flexion could fail to identify the type of instability correctly.

Because of the aforementioned observations, we decided to study in detail the normal patellofemoral joint in the first 60° of flexion. To our knowledge, there have been no studies of the normal patellofemoral relationship in this range of knee flexion; most have been limited to the first 30° of flexion [5, 10, 18, 21]. Martinez et al. [13] studied the joint at 0°, 20°, and 45° flexion, but they did not measure the congruence angles. Their method of deter-

Table 1. Mean values and standard deviations of the three angles at various knee positions

Angle of knee flexion (°)	Patellar tilt angle (°)		Congruence angle (°)		Sulcus angle (°)
	Without contraction	With contraction	Without contraction	With contraction	
0	15.7 ± 8.8	16.5 ± 9.8	18.3 ± 20.8	33.2 ± 21.9	151.9 ± 8.0
10	17.5 ± 8.2	18.3 ± 8.6	4.8 ± 21.5	17.6 ± 21.1	150.2 ± 9.9
20	17.5 ± 7.3	20.2 ± 8.1	–1.5 ± 17.4	4.6 ± 21.8	148.3 ± 9.3
30	17.4 ± 7.7	18.9 ± 8.4	–5.8 ± 17.8	–9.0 ± 15.3	145.1 ± 10.8
40	17.3 ± 6.8	19.5 ± 7.2	–9.3 ± 14.3	–9.7 ± 16.5	138.2 ± 11.0
60	16.4 ± 7.2	17.9 ± 7.7	–13.3 ± 16.8	–6.7 ± 15.5	134.9 ± 12.2

mining patellar centralisation excludes medial and lateral to medial instabilities.

Computed tomography was chosen as the imaging modality in this study because of its lower cost. We also believe that MRI does not offer any advantages over CT scanning for studying patellofemoral relationship. Furthermore, the MRI scanner does not permit more than 30° knee flexion. Recently, we attempted to image knees up to 90° flexion in the hope of obtaining more information, but the CT scanner did not permit more than 70° flexion.

The first study using computed tomography to study the normal position of the patella was reported by Delgado-Martins [5]. That study showed that the patella usually lies laterally and incongruently when the knee is in full extension. More recently, several other studies have reported the same finding [10, 17–20]. The present study agrees with those findings. Eighty-two percent of the patellae had congruence angles greater than 0° in extension. Similarly, Delgado-Martins [5] reported that 87% of patellae were lateralised in extension. This study shows that congruence angles as high as +39° should be considered normal in extension. For this reason, one should be careful when evaluating the images qualitatively. Angles should be measured or a normal patella may be misinterpreted as subluxed. Thus, we emphasise again the importance of determining the normal values at various degrees of flexion.

In contrast to our study, as well as to others, Martinez et al. [14] reported that the patella was generally well centred in extension. It should be noted that they did not measure the congruence angles and their criterion for centralisation was different. Similarly, we do not agree with Inoue et al. [9], who stressed the importance of computed tomography with the knee in full extension. They stated that the normal patella was well centred in extension. That study was different from ours in that the authors used the lateral patellofemoral angle at 0° as a criterion of subluxation. We believe that the lateral patellofemoral angle shows the amount of patellar tilt, and that the congruence angle is the best indicator of subluxation.

At 10° flexion, the tendency is still towards lateralisation. Congruence angles as high as +26° are compatible with normal patellar tracking. Thus, we disagree with Schutzer et al. [18] who stated that all patellae were centred or slightly medial by 10° flexion. They considered a patella subluxed if the congruence angle remained more than 0° at 10° flexion. A support to our observation comes from Kujala et al. [10], who concluded that normal knees were not congruent at less than 30° flexion.

The present study showed that the patella usually moves medially as the knee is flexed. The mean congruence angle becomes negative at 20° and remains increasingly negative as the knee is flexed to 60°. Although the difference in congruence angles was nonsignificant between 20° and 60° flexion, the lower and upper limits of normal values differ, although only slightly, and should be considered separately at each degree of flexion. Only then is it possible to determine the type of abnormal tracking at different knee positions. High standard deviations indicate a great range of normal congruence angles. This certainly means that normal patellae may show large variations in tracking.

At 45° knee flexion Merchant et al. [15] and Aglietti et al. [1] found the mean congruence angles to be –6° and –8°, respectively. The mean congruence angle of –9° at 40° in this study is comparable to those values. The mean congruence angle in full extension was significantly higher than that at 30°. Therefore, no conclusions can be drawn regarding the efficiency of computed tomography over radiographs by comparing computed tomographic images in extension with conventional radiographic images at 30° flexion. The more lateral shift of the patella in extension reported by Sasaki and Yagi [17] is a normal finding. Hence, their methodology seems to be unacceptable.

The normal patellar tilt angle has been studied in detail during the first 30° knee flexion by Schutzer et al. [18, 19]. They found that the patellar tilt angles were in the high positive range and constant between 0° and 30° flexion, but were not less than 8° at any position. Martinez et al. [13] also found the patellar tilt angle to be constant between 0° and 45° flexion. We totally agree with their observations. By the same method of measurement, the patellar tilt angles were not less than 7° at any position, and still remained constant after 30° up to 60° flexion. The lower limit was usually 9°–10°. It is obvious that the lower limit in normal knees should be taken into account to distinguish between normal and tilted patellae. On the other the hand, Kujala et al. [10] found that lateral patellar tilt decreased significantly during the first 30° flexion. Their method of measurement, i.e. the reference lines on both the trochlea and the patella, are quite different. We agree with Schutzer et al. [18, 19] that the posterior femoral condyles should be taken as reference. For similar reasons, we do not agree with Inoue et al. [9], who stated that the lateral patellofemoral angle changed significantly at 0°, 30°, and 45° flexion. The anterior condyles were taken as the reference line in that study. Moreover, another point in that study is that the calculations were made on computed tomographic sections at 0 and on plain radiographs at 30° and 45° knee flexion.

When midpatellar sections are taken, it is not difficult to understand the gradual decrease of the sulcus angle with knee flexion. As the knee is flexed, the patella moves distally and comes into contact with the deeper and more distal part of the trochlea. Thus, a very shallow sulcus angle near extension is an indirect sign of patella alta. It does not indicate trochlear dysplasia. Measuring the sulcus angle at a wide range of flexion seems to be important in that it gives a profile of the femoral trochlea from proximal to distal. High sulcus angles on all sections in a wide range of flexion may be the best indicator of a trochlear dysplasia.

There seems to be a consensus on the gradual decrease of the sulcus angle with knee flexion, although there are some variations between the values. The variations do not appear to be great. 138° at 40° in this study is comparable to Merchant's value at 45° [15]. In contrast, the sulcus angle at 45° was found to be slightly less than 110° by Martinez et al. [13]. They noted significant differences between the sulcus angles at 0°, 20°, and 45°. In our study, the differences at 0°, 10°, and 20° were not significant, but all of them were significantly different from those at 40° and 60°. The sulcus angle values found by Kujala et al. [10] were similar to ours.

The effect of isometric quadriceps contraction on the position of the normal patella is still a matter of controversy. There have been a few studies with inconclusive results. The patients in our study were taught to contract both quadriceps and hamstrings to simulate a more physiological weight-bearing condition. Perhaps the same method was used in other studies, but it was termed "quadriceps contraction". Kujala et al. [10] found no difference in the mean values of lateral patellar displacement with and without isometric quadriceps muscle contraction in extension. Muscle force moved in the patella medially in half of the subjects and laterally in the other half. Martinez et al. [13] analysed their results in a different way and concluded that contraction of the quadriceps muscle had little influence on patellar centralisation. In only 3 out of 20 knees did the patellae became decentralised at full extension and none at 20° and 45°. By their methodology, this means that three patellae were pulled laterally with contraction at full extension. Similarly, 3 out of 20 normal patellae showed minimal subluxation with quadriceps contraction in extension in the study by Schutzer et al. [19]. Delgado-Martins [5] noted that in extension the number of decentralised patellae (87%) increased to 96% with quadriceps contraction, but did not comment on the congruence angles.

Our study provides more solid and clear data than the other studies. This study suggests that the effect of muscle contraction near extension is more significant than mentioned in previous studies. In normal individuals, contraction of the thigh muscles caused lateralisation of the patella except at 30° and 40° flexion. This lateral pull was statistically significant at 0° and 10°. In other words, normal patellae are usually more lateralised during weight-bearing. Eighty-two percent of the patellae were pulled laterally with muscle contraction. It seems that muscle contraction has little or no effect on the position of the patella once it is seated in the trochlea, most likely due to the bony support.

This study attempted to investigate the effect of muscle contraction on patellar tilt. In contrast to the congruence angle, muscle contraction had little influence on patellar tilt.

We attempted to trace the normal patellofemoral relationship in a wide range of knee flexion. The results suggest that one should not rely on axial images taken only in full extension when evaluating patients with anterior knee pain, as this may erroneously lead to a diagnosis of patellar subluxation in a normally tracking patella. Normal values of angles used in assessing patellar malalignment may show great variations at a given knee position. The mean values and limits of normal knees also vary at different flexion angles. The line of muscle pull is usually lateral near extension in normal subjects. Comparison of the dynamic values obtained in this study with those in abnormal patellofemoral joints may reveal useful information. It is hoped that the normal limits of congruence angle, patellar tilt angle, and sulcus angle during the first 60° of knee flexion will add to current knowledge and provide a basis for determining the type of patellar instability at different knee positions, thus giving a better profile of patellar tracking. This is a new concept.

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