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Kinematic and dynamic axial computerized tomography of the normal patellofemoral joint

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Normal patellofemoral eklemin kinematik ve dinamik aksiyel bilgisayarlı tomografisi

Daha önce ve şu anda herhangi bir diz problemi olmayan 14 normal gönüllünün patellofemoral eklem aksiyel bilgisayarlı tomografisi çekildi. 14-16 yaşları arasında (ortalama 25) 11 erkek ve 3 kadın vardı. Uyluk kaslarının hem kontraksiyonu ile hem de kontraksiyonsuz 0°, 10°, 20°, 30°, 40°, 60° fleksiyonda aksiyel görüntüleri alındı. Böylece herbir kişi için 12 görüntü elde edildi. Her görüntüden önce BT midpatellar seviyeye odaklandı. 24 dizin herbirinde 3 ölçüm yapıldı: Kongruans (uyum) açısı (CA), patellar tilt açısı ve sulkus açısı. İstatistiksel hesaplamalar için eşlenmiş t-test, Anova ve Tukey işlemi kullanıldı. PTA nın alt sınırı genellikle 9°-10° idi ve hiç bir diz pozisyonunda 7° nin altında değildi. Kas kontraksiyonu PTA yı her bir fleksiyon derecesinde hafif artırdı. CA O° de ortalama + 18° idi (standart sapma 20.8), bu da normal dizde tam ekstansiyonda CA nın + 39°ye kadar artabileceği anlamına geliyor. 20° ve 60° fleksiyon arasında ortalama değerler negatifleşiyor. 30° ve 40° fleksiyon dereceleri uyluk kasları kontraksiyonu patella lateralizasyonuna neden oluyor. Tam ekstansiyonda ve 10° fleksiyonda (p<0.005) bu lateralizasyon istatistiksel olarak anlamlı (p<0.01). Diz fleksiyonu arttıkça SA olarak azalıyor. 0°, 10°, 20° fleksiyondaki açılar, 40°ve 60° fleksiyondakilere göre daha fazla (p<0.05). Bu çalışma diz fleksiyon derecesine göre CA, PTA ve SA'nın değiştiğini ve normal populasyonda bu açıların büyük varyasyonlar gösterdiğini göstermektedir. Sadece tam ekstansiyonda bir bilgisayarlı tomografi görüntüsüne bağlı kalınmamak, bu normal patellar subluksasyon teşhisi koydurabilir. Bu çalışma değişik diz pozisyonlarında, patellar instabilite tiplerinin belirlenmesi için bir baz ortaya koymakta ve patella için daha iyi bir profil vermektedir. Bu yeni bir konsept. Bunun yanı sıra, bu çalışmada elde edilen dinamik değerlerin patolojik patellofemoral eklemlerden elde edilen sonuçlar ile karşılaştırılması daha iyi bilgi verecektir.

Anahtar kelimeler: *Patellofemoral eklem, bilgisayarlı tomografi*

Kinematic and dynamic axial computerized tomography of the normal patellofemoral joint

Fourteen normal volunteer with no history suggesting previous or current knee pathology underwent axial computerized tomographic examination of the patellofemoral joint. There were eleven men and three whose ages ranged from 10 to 46 years (av. 25 years). Axial images obtained 0°, 10°, 20°, 30°, 40°, and 60° of flexion both with and without contraction of the thigh muscles. Thus, twelve images were obtained for each individual. The CT scanner was foused at the midpatellar level prior to each image. Three measurements were made on twenty-four knees for each individual: congruence angle (CA), patellar tilt angle (PTA), and sulcus angle (SA). Paired t-test, ANOVA, and Tukey's procedure were used for statical calculations. PTA increased slightly from 0° to 20°, and decreased slightly with more flexion (not significant, NS). The lower limit of PTA was usually 9° to 10° and not lower than 7° in any of knee positions. Muscle contraction increased PTA slightly at each degree of flexion (NS). CA was mean + 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 lateralization 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 errroneously lead to adıagnosis 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 of 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 computerized tomography*

Patellar tracking abnormalities are a major cause of anterior knee pain (6, 7, 8, 11). Clinical diagnosis may be difficult because the signs and symptoms often mimic those of other forms of internal derangements of the knee (11). Consequently, various radiographic techniques have been proposed, but the result have been proposed, but the results have been unsatisfactory with most of these procedures (2, 3, 4, 16). Furthermore, axial plain radiographic evaluation of the patellofemoral joint requires knee flexion of at

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least 25°-30°. Thus, 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 computerized tomography (CT) and magnetic resonance imaging for 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. was done at 0°, 20°, and 45° of knee flexion (13).

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

Patients and methods

Fourteen normal volunteers with no history suggesting previous and current knee pathology underwent axial CT examination of the patellofemoral joint. There were eleven men and three women whose ages ranged from 10 to 46 years (av. 25 years). CT images were obtained on all five second body scanner (Toshiba TCT-6005).

Simple wedges were used to place both knees at desired angles of knee flexion with the patient in the supine position. Axial images were obtained at 0°, 10°, 20°, 30°, 40°, and 60° of flexion. For each angle of knee flexion, images were obtainedt 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 each image. Thus, twelve images were obtained for each subject. In other words, measurements were made on twenty-four knees for each subject.

Three measurements were made from each image:1 sulcus angle (SA), formed by the intersection of lines drawn parallel to 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 patella, 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 standart deviations, of the three angles were found for each knee position with and without muscle contraction. 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 difference was noted, Tukey's procedure was used for multiple comparisons. P<0.05 was considered as statistically significant.

Results

The mean values and standart deviations of the three angles are shown on 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 upper limit is important for PTA. The lower limit was usually 9°, to 10° and not lower than 7° in any of knee positions.

Angle of	PTA (°)		CA (°)		SA(°)
knee flexion	C (-)	C(+)	C(-)	C(+)	
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	-5.8+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

Table 1: Mean values and standard deviations of the three angles at various knee positions
C (-): without muscle contraction
C (+): with muscle contraction

CA was mean+18.3° (SD:20.8) at full extension, which means that normal subjects may have CAs as hing as +39. CA was reduced to 4.8° +21.5 at 10° of flexion. When compared to the value at full extension, this decrease was almost at the limit of signifiance. The mean values became encerasingly negative between 20°, 30°, 40°, and 60° flexion were significantly lower than 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 lateralization 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 medialization of the patella (NS).

CAs with muscle contraction decreased with flexion similar to the static condition. When dynamic CAs were compared among themselves, CA at extention was signifiantly higher than those at 10° to 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, angles at 0°, 10°, and 20° flexion were significantly higher then those at 40° and 60° flexion. SA at 30° flexion was significantly higher than that at 60° flexion (p<0.05).

Discussion

Although various conventional radiographic techniques have been proposed to evaluate patellar maligment, there has been general dissatisfaction with most of these procedures (12, 13, 18). The problems have been technical and interpretational. Recently, it has been emphasized 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. In that study, we measured the patellar tilt angle, congruence angle, and sulcus angle at 0° to 40° and at 60° of flexion seperately, compared with normal values, and determined the types of abormality at each knee position. Thus a table demonstrating the types of patellar tracking abnormalities at various knee positions was obtained. That 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 degrees of knee flexion could miss the correct type of instability.

Because of the aforementioned observations, we decided to study in detail the normal patellofemoral joint in the first 60 degres of flexion. To our knowledge, there have been no studies of normal patellofemoral relationship in this range of knee flexion. The studies have usually been limited to the fist 30 degrees of flexion (5, 10, 18, 21). Martinez et al. (13) studies the joint at 0°, 20°, and 45° of flexion. However, they did not measure the congruence angle. Their method of determining patellar centralization excludes the medial and lateral to medial instabilities.

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

The first study using computerized tomography to study the normal position of the patella was reported by Delgado-Martins (5). Their study showed that the patella usually lies lateral and incongruent when the knee is in full extension. More recently, several other studies reported the same finding (10, 17, 20). This study agrees with those findings. 82% of the patellae had congruence angles greater than 0 degrees in extension. Similary, Delgado-Martins (5) reported that 87% of the patellae were lateralized 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, otherwise a normal patella would be ministerpreted as subluxed. Thus, we emphasize 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 centered in extension. It should be noted that they did not measure the congruence angles and their criterion for centralization was different. similary, we do not agree with Inoue et al. (9) who stressed the importace of computed tomography with the knee in full extension. They stated that the normal patella was well centered in extension. That study was different from ours in that, they used the lateral patellofemoral angle at 0° as a criterion for subluxation. We believe that the lateral patellofemoral angle shows the amount of patellar tilt, and that congruence angle is the best indicator of subluxation. At 10° of flexion, the tendency is still towards lateralization. Congruence angles as high as +26° is compatible with a normal patellar tracking. Thus, we disagree with Schutzer et al. (18) who stated that all patellae were centered or slightly medial by 10 degrees of flexion. They considered a patella subluxed if the congruence angle remained more than 0° at 10° of flexion. A support to our observation comes from Kujala et al. (10) who concluded that the normal knees were not congruent at less than 30° of flexion.

This 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 of congruence angles was nonsignificant between 20° and 60°, the lower and upper limits of normal values differ, although slightly, and should be considered seperately at each degree of flexion. It is only then possible to determine the type of abnormal tracking at different knee positions. High values of standart deviation give rise to a great range of normal congruence angles, This certainly means that normal pateallea may show large variations of tracking.

At 45° of knee flexion Merchant (15} and Aglietti (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 their values. Mean CA in full extension was significantly higher than that at 30°. Therefore, no conclusions can be drawn regarding the efficiency of CT over radiographs by comparing CT images in extension with conventional radiographic images at 30° of flexion. More lateral shift of 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° of knee flexion by Schutzer et al. (18, 19). They found that the PTAs were in the high positive range and constant between 0° and 30° of flexion, but were not less than 8 degrees at any position. Martinez et al. (13) also found the PTA to be constant between 0° and 45° of flexion. We totally agree with their observations. By the same method of measurement, the PTAs were not less than 7 degrees at any position, and still remained constant after 30° up to 60° of flexion. The lower limit was usually 9° to 10°. It is obvious that the lower limit of normals 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 significiantly during the first 30° of flexion. Their method of measurement, that is, the reference lines both on the trochlea and the patella are quite different. We agree with Schutzer et al. (18, 19) that posterior femoral condyles should be taken as reference. For similar reasons, we do not agree with Inoue et al. (9) who stated that lateral patellofemoral angle changed significantly at 0°, 30°, and 45° of flexion. Anterior condyles were taken as the reference line in that study. Morever, another point in that study is that the calculations were made on computerized tomographic sections at 0° and on plain radiographs at 30° and 45° of knee flexion.

When midpatellar sections are taken, it is not difficult to understant 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 shollow 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 in gives a profile of the femoral trochlea from proximal to distal. High sulcus angles on all sections at a wide range of flexion may be the best indicator of a trochlear dysplasia.

There seems to be a consenous 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 the 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°. Kujala et all's sulcus angle values were similar to ours (10).

The effect of isometric quadriceps contraction on the position of normal patella is still controversial. There have been few studies the results of which are inconclusive. The patients in our study were taught and instructed to contract both quadriceps and hamstring to simulate a more physiologic weght-bearing condition. Perhaps the same methodology was used in other studies but it was termed as 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 the patella medially in half of the subjects and laterally in the other half. Martinez et al. (13) analyzed their results in a different way, and concluded that contraction of the quadriceps muscle had little influence on patellar centralization. In only three out of twenty knees did the patellae became decentralized at full extension and none at 20° and 45°. By their methodology, this means that there patellae were pulled laterally with contraction at full extension. Similarly, three out of twenty normal patellae showed minimal subluxation with quadriceps contraction in extension in Schutzer et al's study (19). Delgado-Martins (5) noted that in extension the number of decentralized patellae (87%) further 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 lateralization of the patella except at 30° and 40° of flexion. This lateral pull was statistically significant at 0° and 10°. In other words, normal patellae are usually more lateralized during weight-bearing. 82% of the patellae were pulled laterally with muscle contraction. It seemp 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 for the first the time 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.

This study 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 assesing patellar malalignment may show great variations at a given knee position. The mean values and limits of normals also vary at diffrent flexion angles. Line of muscle pull is usully lateral near extension in normal subjects. Comparison of dynamic values obtained in this study with the the normal limits of congruence angle, patellar tilt angle, and sulcus angle during the first 60° of knee flexion will add to the current knowledge, and provide a basis for determining the type of patellar instability at different knee positions and thus give a better profile of patellar tracking. This is a new concept.

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