Patella Alta: Association with Patellofemoral Alignment and Changes in Contact Area During Weight-Bearing

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Background: Patella alta is a condition which may predispose individuals to patellofemoral joint dysfunction. We compared patellofemoral joint alignment and contact area in subjects who had patella alta with subjects who had normal patellar position, to determine the effect of high vertical patellar positions on knee extensor mechanics.

Methods: Twelve subjects with patella alta and thirteen control subjects participated in the study. Lateral patellar displacement (subluxation), lateral tilt, and patellofemoral joint contact area were quantified from axial magnetic resonance images of the patellofemoral joint acquired at 0°, 20°, 40°, and 60° of knee flexion with the quadriceps contracted.

Results: With the knee at 0° of flexion, the subjects with patella alta demonstrated significant differences compared with the control group, with greater lateral displacement (mean [and standard error], 85.4% ± 3.6% and 71.3% ± 3.0%, respectively, of patellar width lateral to the deepest point in the trochlear groove; $p = 0.007$), greater lateral tilt (mean, 21.6° ± 1.9° and 15.5° ± 1.8°; $p = 0.028$), and less contact area (157.6 ± 13.7 mm^2 and 198.8 ± 14.3 mm^2; $p = 0.040$). Differences in displacement and tilt were not observed at greater knee flexion angles; however, contact area differences were observed at all angles evaluated. When data from both groups were combined, the vertical position of the patella was positively associated with lateral displacement and lateral tilt at 0° of flexion and was negatively associated with contact area at all knee flexion angles.

Conclusions: These data indicate that the vertical position of the patella is an important structural variable that is associated with patellofemoral malalignment and reduced contact area in patients with patella alta.

Patellofemoral pain is one of the most common disorders of the knee, affecting as many as 30% of physically active individuals[1,2]. The etiology of patellofemoral pain is believed to be related to patellar maltracking and subsequent elevated joint stress[3-6]. Malalignment of the patellofemoral joint may produce abnormal contact between the patella and the femur, therefore reducing the load-bearing surface over which the forces from the extensor mechanism are transmitted to the femur[3,7].

Patella alta (high position of the patella) is a clinical condition often associated with patellofemoral instability and pain[5,8,9]. A consequence of patella alta is reduced osseous stability provided by the femur, as a higher patella articulates with more shallow portions of the proximal trochlear groove[8-12]. Although it is assumed that the higher the position of the patella, the greater the degree of patellar instability[6,8], an investigation has shown that the association between the position of the patella relative to the femur and patellofemoral malalignment is weak[6]. However, a limitation of that study was that patellar malalignment was quantified from axial radiographs made with the quadriceps muscles relaxed. This is an important limitation because contraction of the quadriceps muscles exerts a laterally directed force on the patella[7]. Therefore, it is possible that the previous study[6] underestimated the association between patella alta and patellofemoral joint malalignment.

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TABLE I Subject Characteristics

Patient Characteristics	Control Group* (n = 13)	Patella Alta Group* (n = 12)
Age *(yr)*	28.1 ± 3.9	25.1 ± 3.4
Height *(cm)*	163.4 ± 3.8	162.6 ± 4.9
Weight *(kg)*	56.2 ± 6.3	58.8 ± 9.3
Insall-Salvati ratio†	1.03 ± 0.09	1.29 ± 0.10‡
Patellar width *(mm)*	40.0 ± 1.99	40.7 ± 1.4
Articular surface length *(mm)*	35.4 ± 4.18	35.5 ± 3.4

*The values are given as the mean and the standard deviation. †Calculated as the patellar tendon length divided by the length of the patella. ‡The difference between the groups was significant ($p < 0.05$).

Previous investigations have hypothesized that the increased malalignment observed in patients with patella alta leads to reductions in the load-bearing surface area[9,13]. Although we previously reported that persons with patella alta have reduced patellofemoral joint contact area and elevated stress[13], no study we are aware of has simultaneously documented changes in patellofemoral joint alignment and contact area associated with patella alta as a function of knee flexion angle. The purpose of this study was to measure patellar height, alignment, and contact area with the quadriceps muscles contracted in order to assess how these variables interact in patients with patella alta.

Materials and Methods

Twenty-five women ranging in age from nineteen to thirty-four years participated in this study (Table I). Prior to enrollment in the study, 205 local university students were screened for patella alta. Screening consisted of simple caliper measurements of patellar height (base to apex) and patellar tendon length (apex to tibial tuberosity). Individuals with patellar tendon lengths that exceeded patellar heights by ≥20% were enrolled in the study as potentially having patella alta[5]. However, the actual inclusion of a subject into the patella alta group was made by quantitative radiographic measurements.

This investigation was approved by the University of Southern California institutional review board, and each subject gave his or her informed consent for participation in the study prior to enrollment. Subjects were then screened with varus-valgus stress, anterior-posterior drawer, and the McMurray[14] tests and were excluded on the basis of tibiofemoral instability, meniscal injury, or previous knee surgery. Additionally, subjects were excluded if they reported being pregnant or possibly pregnant or if they had an implanted biological device, such as a pacemaker, cochlear implant, or clips, which could interact with the magnetic field during imaging. Subjects were not included or excluded on the basis of pain.

Magnetic resonance images of the knee were acquired with a 1.5-T Signa scanner (GE Medical Systems, Milwaukee, Wisconsin). Sagittal images of the knee were obtained with use of a T1-weighted spin-echo pulse sequence (repetition time, 350 ms; echo time, 10 ms; number of excitations, 1; field of view, 20 × 20 cm; matrix, 256 × 256; and slice thickness, 10 mm) and two 12.7-cm receive-only coils. Axial images of the patellofemoral joint were acquired with use of a fat-suppressed fast spoiled gradient recalled echo (FSPGR) pulse sequence

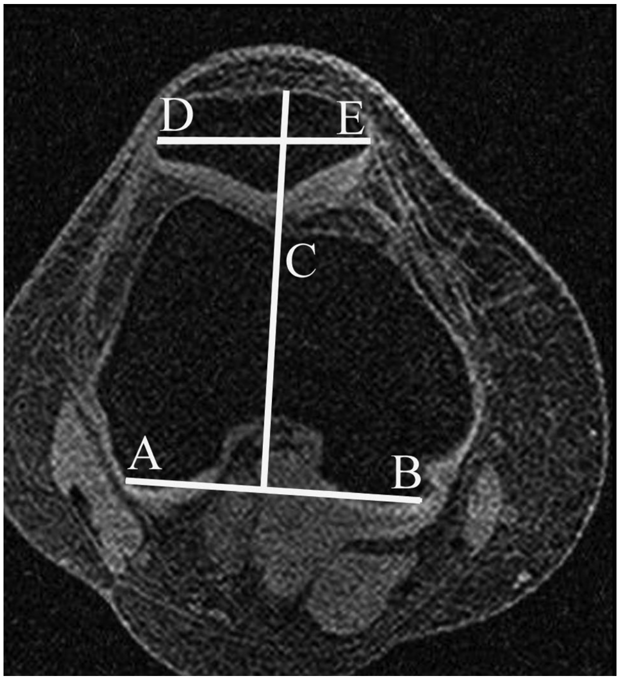

Fig. 1

Lateral patellar displacement was measured with use of the bisect offset index. The bisect offset was measured by drawing a line connecting the posterior femoral condyles (AB) and projecting a perpendicular line anteriorly through the deepest point (C) of the trochlear groove. This line intersected a patellar width line, which connected the widest patellar points (DE). The bisect offset quantified lateral displacement as a percentage of patellar width. Lateral patellar tilt was the angle in degrees between the posterior condylar line (AB) and the maximum patellar width line (DE).

(repetition time, 8.2 m; echo time, 1.5 ms; number of excitations, 1; spectral inversion for fat suppression; field of view, 20 × 20 cm; matrix, 256 × 256; and slice thickness, 2 mm) and two 12.7-cm receive-only coils. Images were interpolated to a 512 × 512 matrix postacquisition as previously described[1,15].

Subjects were imaged at four knee flexion angles (0°, 20°, 40°, and 60°) with the quadriceps muscles contracted. Quadriceps resistance was achieved with use of a custom-made, magnetic resonance imaging-compatible loading apparatus[15] in which the trunk and shoulders of the subject were strapped onto a mobile sled and, on the extremity of interest, the foot was attached to a stationary footplate. The sled was loaded with epoxy weights (25% of the subject's body weight), and the subject was asked to extend the leg until the desired knee joint angle was achieved and to hold that position during imaging. We previously determined that a loading magnitude of 25% of body weight was sufficient to activate the quadriceps but was not so difficult that it caused motion artifact during imaging[15]. Hence, the joint was loaded isometrically under simulated weight-bearing conditions. All subjects were allowed to practice this maneuver until they could consistently maintain the desired joint positions. Joint angles were set with a standard goniometer and sagittal magnetic resonance images of the knee were then acquired. Following a one-minute rest period, the knee joint angle was reset and axial magnetic resonance images of the patellofemoral joint were acquired under the same conditions. If the joint angles were different before and after imaging or there was motion artifact in the images, the patient was assumed to have moved and the protocol was repeated. The acquisition times for the sagittal and axial images were 120 seconds and thirty-nine seconds, respectively.

Prior to analysis, all images were magnified (×1.5) and calibrated with use of Scion Image software (Scion, Frederick, Maryland). The position of the patella was quantified with use of the Insall-Salvati ratio[5,13,16]. Briefly, the length of the patellar tendon was divided by the length of the patella to yield this ratio[5]. A ratio of >1.2 indicated the presence of patella alta, whereas a ratio from 0.8 to 1.2 indicated normal patellar position[5]. On the basis of these objective measures, twelve (6%) of the 205 subjects were determined to have patella alta and thirteen of the remaining 193 subjects with normal patellar position were enrolled as age, height, and weight-matched controls. Only one of the individuals initially screened and objectively determined to have patella alta was a man. This apparent gender bias toward women, and previous data suggesting gender differences in patellofemoral biomechanics[17], led us to exclude the man from the study.

Axial images were screened to determine which image contained the maximum patellar width. With use of this image, two measurements of patellofemoral alignment were obtained[18]. First, mediolateral patellar displacement was assessed with use of the bisect offset index[18,19]. The bisect offset was measured by drawing a line connecting the posterior femoral condyles and projecting a perpendicular line anteriorly through the deepest portion of the trochlear groove. This line intersected the patellar width line, which connected the widest points of the patella (Fig. 1). To obtain data when the posterior femoral condyles were inferior to the widest portion of the patella, coordinates

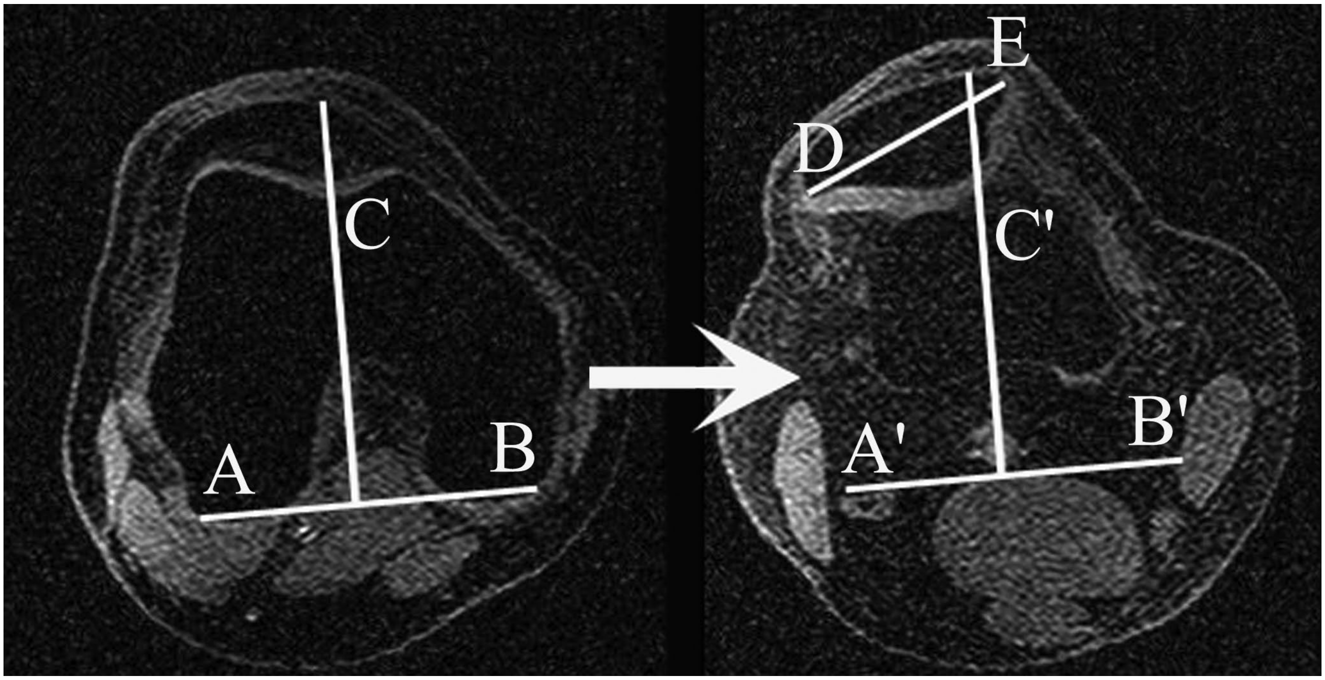

Fig. 2

Lateral patellar displacement and lateral patellar tilt were quantified when the patella was above the trochlear groove. The posterior condylar line (AB) and the deepest portion of the trochlear groove (C) were localized on the slice containing the maximum diameter of the femoral condyles (left). These landmarks (A, B, and C) then were transferred to the image containing the maximum patellar width (DE) (right).

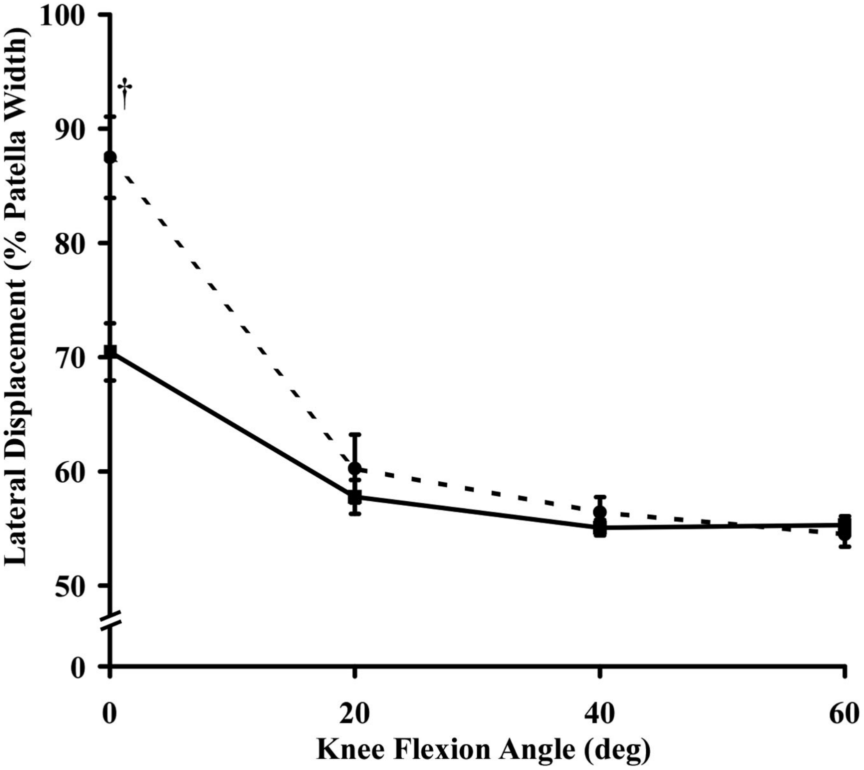

Fig. 3

Lateral patellar displacement as a function of knee flexion angle in controls (solid line) and subjects with patella alta (dotted line). Error bars indicate one standard error. †The difference between the patella alta and the control groups at 0° of knee flexion was significant ($p < 0.05$).

from the posteromedial and posterolateral femoral condyles and the deepest portion of the trochlear groove were transferred to the image containing the maximum patellar width (Fig. 2). This procedure provided identical reference points between subjects with different patellar heights. The bisect offset represented the percentage of patellar width lateral to the deepest portion of the trochlear groove.

Mediolateral patellar tilt was assessed with use of the patellar tilt angle[18,19]. The patellar tilt angle was the angle formed between the line depicting the maximum patellar width and the line joining the posterior femoral condyles (Fig. 1). As previously noted, in knees in which the maximum patellar width was superior to the posterior femoral condyles, coordinates from the appropriate landmarks were transferred to the image containing the maximum patellar width (Fig. 2). Patellar tilt measurements were reported in degrees. Acceptable intraobserver and interobserver reliability (intraclass correlation coefficient, ≥0.90) for the bisect offset and patellar tilt measurements have been previously reported[19].

The contact area was measured from the sequential axial plane images of the patellofemoral joint. Contact was defined as areas in which no distinct separation could be found between the patella and the femur. A curvilinear line of contact between the patella and the femur was drawn and then measured on each slice. The length of contact on each slice was multiplied by the 2-mm slice thickness to yield an intraslice contact area. The areas of contact from each sequential image were summed to obtain a total patellofemoral joint contact area[15,20]. All contact area measurements were reported in square millimeters. This contact area method has been shown to be reliable and comparable (intraclass correlation coefficient, ≥0.91) with contact area measurements obtained with use of Fuji pressure-sensitive film in cadaver specimens[20]. All radiographic measurements were made twice by the same investigator and were averaged for final analysis.

Initial statistical analysis included the Shapiro-Wilk test[21] and the Levene[22] test to screen the data for assumptions of normality and homogeneity of variances. Two-way repeated-measures analyses of variance were used to compare groups and knee flexion angles (main effects) and interactions between groups and knee flexion angles (interactions). These analyses were repeated for lateral patellar displacement, lateral patellar tilt, and contact area. When significant interactions between group and knee flexion angle were observed, post hoc Tukey tests were used to identify group differences at individual knee flexion angles.

Pearson correlation coefficients were used to assess the association of vertical patellar position with lateral patellar displacement, lateral tilt, and contact area at all knee flexion angles. Stepwise multiple-regression analysis was used to de-

TABLE II Correlation Coefficients Between the Insall-Salvati Ratio and the Lateral Displacement, Lateral Tilt, and Contact Area at Each Knee Flexion Angle

	Knee Flexion Angle (r^2)			
	0°	20°	40°	60°
Lateral displacement	0.365*	0.037	0.026	0.009
Lateral tilt	0.274*	0.014	0.001	0.009
Contact area	0.404*	0.342*	0.238*	0.196*

*The correlation with the Insall-Salvati ratio is significant ($p < 0.05$).

termine which variables (displacement, tilt, and/or Insall-Salvati ratio) were the best predictors of contact area at each knee angle. Statistical analyses were performed with use of SPSS statistical software (version 11.5; SPSS, Chicago, Illinois) with a significance level of $p < 0.05$.

Results

Lateral patellar displacement increased as the knee was extended in both the patella alta and control groups ($p < 0.001$) (Fig. 3). However, lateral patellar displacement increased more dramatically as the knee extended in the patients with patella alta ($p < 0.001$) (Fig. 3). Post hoc tests demonstrated that patients with patella alta had greater lateral displacement compared with subjects with normal patellar position at 0° of knee flexion (mean [and standard error], 85.4% ± 3.6% and 71.3% ± 3.0%, respectively, of patellar width lateral to the midline; $p = 0.007$) (Fig. 3). On the basis of the numbers, no significant differences in lateral patellar displacement were observed at 20°, 40°, and 60° of knee flexion.

Similarly, lateral patellar tilt increased as the knee was extended in both the patella alta and control groups ($p < 0.001$) but increased more dramatically as the knee extended in the patients with patella alta ($p < 0.001$) (Fig. 4). Post hoc tests demonstrated that patients with patella alta had greater lateral tilt compared with subjects with normal patellar position at 0° of knee flexion (mean and standard error, 21.6° ± 1.9° and 115.5° ± 1.8°, respectively; $p = 0.028$) (Fig. 4). On the basis of the numbers, no significant difference between the groups with respect to lateral patellar tilt was observed at 20°, 40°, or 60° of knee flexion.

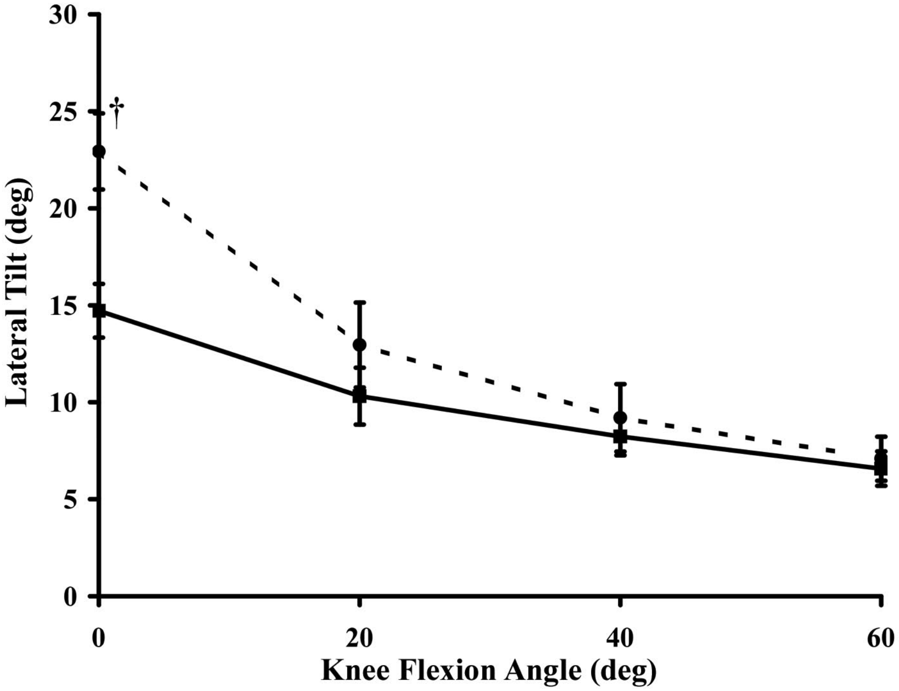

Fig. 4

Lateral patellar tilt as a function of knee flexion angle in controls (solid line) and subjects with patella alta (dotted line). Error bars indicate one standard error. †The difference between the patella alta and the control groups at 0° of knee flexion was significant ($p < 0.05$).

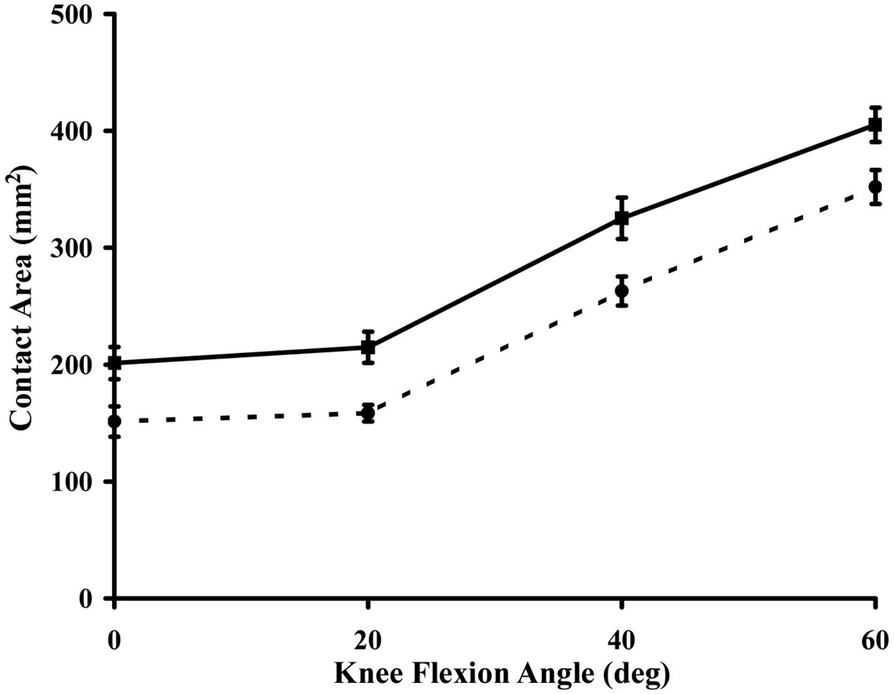

Fig. 5

Patellofemoral joint contact area as a function of knee flexion angle in controls (solid line) and subjects with patella alta (dotted line). There was a significant reduction in contact area in the patients with patella alta across all knee flexion angles tested ($p < 0.001$). Error bars indicate one standard error.

As the knee extended, contact area declined in both the patella alta and control groups ($p < 0.001$). At 0° of flexion, the contact area was 157.6 ± 13.7 mm^2 for the subjects with patella alta and 198.8 ± 14.3 mm^2 for the control group ($p = 0.040$). At all knee flexion angles, subjects with patella alta had significantly less patellofemoral joint contact area compared with subjects with normal patellar position (mean and standard error, 231.2 ± 9.1 mm^2 and 286.7 ± 8.8 mm^2, respectively; $p < 0.001$) (Fig. 5). Although there were significant differences between groups at each knee flexion angle, the largest difference between the groups was observed at 20° of knee flexion (mean and standard error, 158.5 ± 10.6 mm^2 and 214.9 ± 10.2 mm^2, respectively).

The vertical position of the patella was found to be positively associated with lateral patellar displacement ($r^2 = 0.365$, $p < 0.020$) and lateral patellar tilt ($r^2 = 0.274$, $p = 0.002$) at 0° of knee flexion (Table II). However, at 20°, 40°, and 60° of flexion, these correlations were not significant, with the number of subjects studied. The vertical position of the patella was negatively correlated with the patellofemoral joint contact area at all knee flexion angles evaluated ($r^2 = 0.404$ to 0.196, $p < 0.05$), with greater degrees of patella alta associated with less contact area (Table II). Stepwise regression revealed that the vertical position of the patella was the only significant predictor of contact area at any knee flexion angle tested ($p = 0.001$ to 0.027). Lateral displacement and tilt were not found to be significant predictors (r^2=0.136 to 0.248, $p > 0.05$) of contact area at any knee flexion angle with the number of subjects studied.

Discussion

Our data demonstrate that, on the average, subjects with patella alta had 20% more lateral patellar displacement and 39% more lateral patellar tilt than subjects with normal patellar position at 0° of flexion. Additionally, the subjects with patella alta had, on the average, 19% less contact area than the control subjects over the range of 0° to 60° of flexion. The observation that patients with patella alta had greater amounts of malalignment is consistent with previous reports[8,9]. Similarly, the observation that patellofemoral contact areas were reduced in patients with patella alta supports the findings of previous investigations[9,13].

The vertical position of the patella was found to be positively correlated with measures of patellar malalignment, explaining 37% of the variance ($r^2 = 0.365$) in lateral patellar displacement and 27% of the variance ($r^2 = 0.274$) in lateral patellar tilt at 0° of flexion. The strength of the association between the vertical position of the patella and the amount of malalignment was considerably higher than that described in the study by Moller et al.[23], who reported that it explained only 5% of the variance in the congruence angle. The difference between the findings of the current study and those of Moller et al.[23] can be attributed to differences in experimental design. In the current study we imaged the patellofemoral joint with the quadriceps contracted, whereas the previous study had axial radiographs of the patellofemoral joint made at 45° of knee flexion with the quadriceps relaxed. Given that patellar instability typically is observed in the last 30° of knee extension[24] with quadriceps contraction, it would appear that imaging the joint under these conditions would yield the best diagnostic information. As a result of the inherent osseous stability afforded by the trochlear groove, lateral excursion of the patella would likely be limited when the joint was imaged at 45° of flexion. Therefore, our data suggest that in order to obtain diagnostic information concerning malalignment, the patellofemoral joint should be imaged with the knee in full extension.

The vertical position of the patella explained 20% to 40% of the variance in contact area in the range of 0° to 60° of flexion, on the basis of the r^2 values. These findings were not entirely unexpected as subjects with patella alta have a higher patella relative to the femur and, therefore, less osseous stability than subjects with normal patellar position. The consequence of the elevated patellar position is that the magnitude of the contact area is lower than that observed in normal individuals. For example, the contact area at 40° of knee flexion in the patella alta group was similar to the magnitude of contact area at 20° of knee flexion for the group with normal patellar height. Similarly, the contact area at 60° of knee flexion in the patella alta group was similar to the magnitude of contact area at 40° of knee flexion for the group with normal patellar height. Elevated joint stress (force divided by contact area) has been implicated in patellofemoral dysfunction and pain[3,13,25]. Assuming that quadriceps forces and joint reaction forces are similar between individuals with patella alta and those with normal patellar position[13,26], it is reasonable to expect larger joint stresses in patients with patella alta compared with those with normal patellar position. This theoretical concept has been modeled in patients with patella alta during gait[13], but the current data provide a mechanistic explanation for the elevated stress hypothesis.

We expected that the increased patellofemoral joint malalignment in the patella alta group would contribute to a reduced contact area. However, this does not appear to be the case, as contact areas were systematically lower in the patients with patella alta, while malalignment differed only at 0° of flexion. These data, together with the multiple regression results, suggest that reductions in contact area are the result of the higher vertical position of the patella and are not necessarily related to malalignment. These observations warrant careful reconsideration of the previously accepted cause-and-effect relationship between patellofemoral malalignment and decreased patellofemoral weight-bearing surface area, at least in patients with patella alta. Future investigations are necessary to understand how changing alignment in these patients can affect patellofemoral contact area and pain. ■

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