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# Patellofemoral Malalignment in Adolescents

## Computerized Tomographic Assessment with or without Quadriceps Contraction

Vincenzo Guzzanti,*†‡ MD, Antonio Gigante,† MD, Antonio Di Lazzaro,* MD, and Carlo Fabbriciani,† MD

*From *"Bambino Gesù" Children's Hospital, Institute of Scientific Research, Division of Orthopaedics, and the †Catholic University of the Sacred Heart, School of Medicine, Department of Clinical Orthopaedics, Rome, Italy*

### ABSTRACT

Twenty-seven adolescents with anterior knee pain with or without patellar instability were studied by computerized tomography to detect patellofemoral malalignment. The examination was performed with and without quadriceps contraction with the knee flexed to 15°. Congruence angle, patellar tilt angle, sulcus angle, and trochlear depth were measured. This investigation showed the well-known types of patellofemoral malalignment with quadriceps relaxed (tilted, lateralized, lateralized, and tilted patella) and, in 52% of cases, revealed changes in type and severity with quadriceps contraction (in 41%, lateralization and tilting were markedly more evident; in 11%, the type of malalignment changed). The results demonstrate that, in addition to assessment with quadriceps relaxed, computerized tomography with quadriceps contraction is a useful adjunct to diagnose and define the type of malalignment in particularly difficult circumstances.

Patellofemoral malalignment constitutes a diagnostic and therefore therapeutic problem that is not always easily solved in adolescents. In the first place, by clinical findings (anterior knee pain, patellar instability, giving way, swelling, pseudolocking, grating, Q angle), diagnosis may be elusive in some instances. Therefore, it is necessary to exclude other abnormalities that often occur in this age group that can cause anterior knee pain.[26] Secondly, the identification of disorders of patellofemoral alignment calls for diagnostic means that can visualize the patellofemoral joint with the knee in the first degrees of flexion.

Several authors[8,15,16,18] have demonstrated that for degrees of flexion exceeding 25° to 30°, it is possible to observe the tendency of the patella to recenter in patients with patellofemoral malalignment. Furthermore, it is necessary to take into consideration the fact that malalignment that is responsible for patellofemoral abnormalities often appears to be a dynamic phenomenon.[6] Hence, the traditional tangential radiographs can no longer be considered reliable in identifying patients with patellofemoral malalignment because of various technical problems (such as difficulties in visualizing the patellofemoral joint at 25° or less of flexion, difficulty in evaluation with quadriceps contraction, absence of a definite reference plane for measurement, overlapping of images, no detection of minimal rotational malpositioning).[15,21,22,24]

In recent years, the use of computerized tomography (CT) has made it possible to obtain without distortion images of axial sections of the patella with the knee in the first 30° of flexion and with the femoral condyles as a reference plane.[5] Various authors have identified by CT some parameters of assessment of the patellofemoral joint in normal subjects and in patients with patellofemoral pain.[10,13,14,19,22] As a test for patellar malalignment, CT was more sensitive and specific than traditional tangential radiographs.[1,2,13] It has also permitted the patellofemoral joint to be studied with the quadriceps contracted so that the dynamic effects of the quadriceps muscle are taken into account. However, the few authors who have performed CT with quadriceps contraction did not focus their attention on adolescents and reported discordant results.[7,17,20,21]

In this study we have performed CT examination on adolescents suspected of having patellofemoral malalignment.

‡ Address correspondence and reprint requests to: Vincenzo Guzzanti, MD, Divisione di Ortopedia e Traumatologia, Sede di Roma, Ospedale Pediatrico Bambino Gesú, Istituto di Ricerca Scientifica, Piazza S. Onofrio, 4, 00165, Rome, Italy.

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We systematically performed CT examinations with quadriceps both relaxed and contracted to gain further insight into the above problems.

## MATERIALS AND METHODS

We performed CT examinations on 27 patients (54 knees) aged between 11 and 17 years (median age, 14). Of these, 21 were female and 6 were male patients. We considered patients who had anterior knee pain with or without a feeling of patellar instability. Nine of these patients occasionally reported controlateral symptoms, but these were not very troublesome.

Patient exclusion criteria were 1) age less than 11 years (in that assessment of CT images is more difficult and less reliable), and 2) habitual and recurrent patellar dislocation. Moreover, we excluded patients with anterior knee pain caused by other problems such as late effects of trauma, meniscal injury, apophysitis, osteochondritis dissecans, synovial plica syndrome, overuse syndrome, and rheumatoid arthritis.

We performed CT examinations on a control group of 20 (10 male and 10 female) adolescents who had no signs or symptoms related to the patellofemoral joint. The median age of the control group was 14 years (range, 11 to 17) (Table 1). We randomly selected either the right or the left knee of each control on the basis of the use of a random-number generating program (Casio Scientific Calculator fx-88, Casio Computer Co., Ltd., Tokyo, Japan) attributing right knees to odd numbers.

The CT examination was performed with Siemens Somatom DR-H C2 equipment (Siemens Aktiengesellschaft, Medical Engineering Group, Erlanger, Federal Republic of Germany) (4-second scanning time, 512 × 512 reconstruction matrix, 2-mm slice thickness, 125 kV, 460 mAs). Patients underwent no therapy before CT. The tomogram-scan technique was used to identify the best CT sections. Each complete CT examination necessitated from six to nine sections. The system used involved radiation exposure in the order of 1 rad in the area examined and 10 Mrads to the gonads (diffused radiation was limited to a radius of 10 cm from the site examined) for each tomogram[4] (in comparison the amount of radiation from a standard dental radiograph, which equals radiation exposure of 600 to 1200 Mrad in the area examined).

A CT of both knees was performed with the patient in the supine position, the patient positioning being similar to that described by other authors.[10–17] The knees were free from skin fixation, that is, able to modify patellar position. The ankles were fixed by felt strips to prevent external foot rotation caused by muscle relaxation. Whereas some authors perform CT with the knee fully extended,[13–20] our examinations were performed with the knee flexed to 15°. As a matter of fact, other authors[14,17,22] claim that when the knee is fully extended, even asymptomatic patients may appear to have malalignment, especially when the quadriceps is contracted.[21] Schutzer et al.,[22] for example, demonstrate that from 0° to 5° of flexion a lateralized patella may be normal, but from 10° of flexion and up, a lateralized patella is abnormal. Hence, we believe that flexion of the knee to 15° makes it possible to increase the specificity of the method in that this reduces false-positives to a minimum without affecting the sensitivity of the method. A quite stiff support has been placed under the popliteus to keep the knees flexed to 15°.

To avoid errors in measurements, we positioned the patient so that the plane of the femoral condyle was perpendicular to the section plane. This section cut through the widest diameter of the patella (Fig. 1), which permitted the best view of the patellofemoral joint for measurement of the tomogram parameters. The CT examination was performed with quadriceps relaxed and with maximal isometric voluntary contraction of the quadriceps muscle.

By contracting the quadriceps, the knees were in 15° of flexion, which raised the heels from the bed. In the contraction phase, external tibial rotation was restrained by securing the ankles with felt strips and by using some radiograph-transparent pillows laterally placed to the leg. The patella is on the upper end of the trochlea when the knee is flexed to 15° and the quadriceps is relaxed. With quadriceps contraction the patella rises 0.3 to 1 cm and becomes lightly lateralized. All of this is the result of a complex balance between physiologic valgus forces and antagonist forces that restrain the patellar tilting and lateralization. Therefore, by CT examination with quadriceps contraction, the patellar and femoral profile was more or less altered from CT examination with quadriceps relaxed, regardless of the fixation device used. However, CT examination in the control group permitted us to evaluate the normal range of the CT parameters with and without quadriceps contraction.

The tomograms obtained were analyzed considering 1) the congruence angle (CA) (Fig. 1A), 2) the congruence angle with quadriceps contraction (CAc), 3) the patellar tilt angle (PTA) (Fig. 1B), 4) the patellar tilt angle with quadriceps contraction (PTAc), 5) the sulcus angle (SA) (Fig. 1C), and 6) trochlear depth (TD) (Fig. 1D). The SA and TD were measured only with quadriceps relaxed. The reference points for measuring CAc and PTAc were slightly different from those of CA and PTA because of minimal variations of the level of tomographic sections.

Statistical analysis was performed by using the analysis of variation (ANOVA) test or the Student's $t$-test on paired or unpaired data.

TABLE 1
Anthropometric data (mean ± SD)

| | Age (years) | Height (cm) | Weight (kg) | Q angle |
|---|---|---|---|---|
| Control group | | | | |
| Males | 14.5 (1.3) | 163 (10) | 52 (12) | 20.5 (2.4) |
| Females | 14.0 (1.8) | 156 (7) | 47 (8) | 20.0 (2.8) |
| Total | 14.2 (1.5) | 159 (9) | 50 (10) | 20.2 (2.6) |
| Patients | | | | |
| Males | 13.7 (2.0) | 159 (11) | 47 (11) | 19.1 (2.8) |
| Females | 14.8 (1.5) | 156 (6) | 48 (7) | 19.4 (3.4) |
| Total | 14.5 (1.7) | 157 (8) | 48 (8) | 19.4 (3.0) |

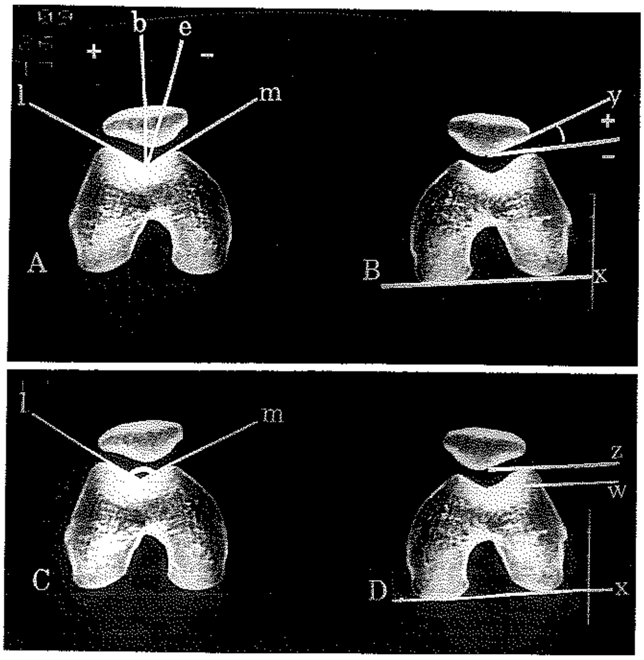


**Figure 1.** A, the CA lies between the bisector of the SA (b) and a line drawn between the deepest point of the trochlea and the edge of the patellar crest (e). The CA reported by Schutzer et al.[21] corresponds to the CA described by Merchant et al.[18] for the evaluation of the patellar axial roentgenogram at 45° of flexion. All of these parameters are identified by a line drawn through the posterior border of the femoral condyles, which is used as a base line (x). B, the PTA is identified by the intersection of a line parallel to the lateral facet of the patella (y) and the base line (x). C, two lines drawn from the deepest point of the trochlea, one passing across the edge of the medial chondyle (m) and the other across the edge of the lateral condyle (l), define the SA; D, TD (in millimeters) is determined by drawing two lines parallel to the base line, one passing tangential to the edge of the lateral condyle (z) and the other passing through the deepest point of the femoral trochlea (w).

## RESULTS

Some anthropometric data of the control group and the patients are listed in Table 1. The results of CT measurements are shown in Tables 2 through 4.

### Control group (20 knees)

The differences between control knees and symptomatic knees were significant for all of the CT variables (unpaired *t*-test) (Table 2). In none of the control knees were CA and CAc higher than 0° and +4°, respectively, nor PTA and PTAc less than 8°. Therefore, we took 0°, +4°, and +8° as the normal limit values for CA, CAc, PTA, and PTAc, respectively.

### Patients

*Examination with quadriceps relaxed (54 knees).* The differences between symptomatic and controlateral knees for CA, PTA, SA, and TD are shown in detail in Table 3 (paired *t*-test). We observed patellofemoral malalignment in both symptomatic and controlateral knees. Malalignment detected with quadriceps relaxed was typed according to the classification of Schutzer et al.[21,22] as follows: Type I—lateralized patella, 13 knees (24.1%) (Fig. 2A); Type II—lateralized and tilted patella, 24 knees (44.4%) (Fig. 2B); Type III—tilted patella, 12 knees (22.2%) (Fig. 2C).

Five knees (9.3%) showed normal patellofemoral alignment with the patella centered (CA less than 0°) and not tilted (PTA higher than 8°) with quadriceps relaxed (Fig. 3A).

The mean SA was 146.4° ± 5.0° in Type I, 151.5° ± 12.8° in Type II, and 139.7° ± 5.3° in Type III. The difference between Types I, II, and III was significant (ANOVA test, $P < 0.05$).

The mean TD was 7.1 ± 1.4 mm in Type I, 4.9 ± 3.3 mm in Type II, and 9.0 ± 1.3 mm in Type III. The difference between the three types was highly significant (ANOVA test, $P < 0.001$).

*Examination with quadriceps contraction (54 knees).* In the symptomatic knees the mean CAc was 25.3° and in the controlateral knees it was 20.0°. This difference was highly significant (paired *t*-test, $P < 0.001$) (Table 3). In the symptomatic knees the mean PTAc was 4.4° and in the controlateral knees it was 6.2° (significant difference, paired *t*-test, $P < 0.01$) (Table 3).

In 26 knees (48.2%), CT examination with quadriceps in contraction gave the same findings as CT examination with quadriceps relaxed, i.e., type and severity of malalignment were identical. In the remaining 28 knees (51.8%), CT examination with quadriceps in contraction gave different

TABLE 2
CT parameters in control (C) and symptomatic (S) knees (mean ± SD)[a]

| | Males | | Females | | Total | |
|---|---|---|---|---|---|---|
| | 10 C | 6 S | 10 C | 21 S | 20 C | 27 S |
| CA | −11.6 (8)[a] | 20.0 (16)[a] | −13.5 (8)[a] | 13.8 (21)[a] | −12.5 (8)[a] | 15.4 (21)[a] |
| PTA | 13.5 (5) NS | 10.3 (7) NS | 15.6 (5)[b] | 3.2 (10)[b] | 14.5 (5)[b] | 5.0 (10)[b] |
| CAc | −10.7 (8)[a] | 26.0 (20)[a] | −12.3 (8)[a] | 25.1 (23)[a] | −11.5 (8)[a] | 25.3 (22)[a] |
| PTAc | 13.4 (5)[b] | 9.9 (8)[b] | 14.5 (5)[b] | 2.5 (11)[b] | 13.9 (5)[b] | 4.4 (11)[b] |
| SA | 124 (8)[a] | 146 (6)[a] | 130 (7)[a] | 148 (12)[a] | 127 (8)[a] | 147 (10)[a] |
| TD (mm) | 12.9 (2)[a] | 7.3 (2)[a] | 11.3 (2)[a] | 6.6 (3)[a] | 12.1 (2)[a] | 6.8 (3)[a] |

[a] Differences between means using unpaired *t*-test. [a], $P < 0.001$; [b], $P < 0.01$; NS, $P > 0.05$.

TABLE 3
CT parameters in symptomatic (S) and controlateral (CL) knees (mean ± SD)[a]

| | Males | | Females | | Total | |
|---|---|---|---|---|---|---|
| | 6 S | 6 CL | 21 S | 21 CL | 27 S | 27 CL |
| CA | 20.0 (16)[b] | 12.7 (14)[b] | 13.8 (21)[a] | 7.8 (20)[a] | 15.4 (21)[a] | 9.0 (19)[a] |
| PTA | 10.3 (7) NS | 12.7 (8) NS | 3.2 (10)[a] | 6.3 (10)[a] | 5.0 (10)[b] | 8.0 (10)[b] |
| CAc | 26.0 (20)[b] | 19.1 (19)[b] | 25.1 (23)[a] | 20.3 (23)[a] | 25.3 (22)[a] | 20.0 (22)[a] |
| PTAc | 9.9 (8)[b] | 10.9 (6)[b] | 2.5 (11)[a] | 4.4 (10)[a] | 4.4 (11)[b] | 6.2 (10)[b] |
| SA | 146 (6) NS | 144 (4) NS | 148 (12) NS | 148 (12) NS | 147 (10) NS | 147 (10) NS |
| TD | 7.3 (2) NS | 7.0 (2)NS | 6.6 (3) NS | 6.4 (3) NS | 6.8 (3) NS | 6.6 (3) NS |

[a] See footnote at Table 2 for statistical descriptions.

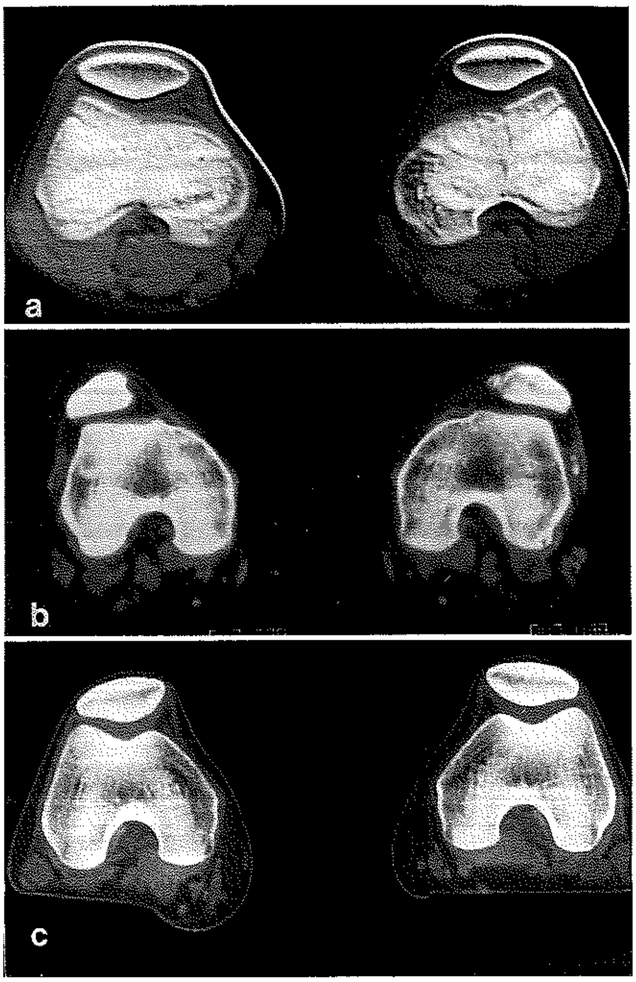

**Figure 2.** Types of patellar malalignment. A, Type I—lateralized patella; B, Type II—lateralized and tilted patella, marked bilateral hypoplasia of the femoral trochlea is evident; and C, Type III—tilted patella.

results from CT examination with the quadriceps relaxed. When the quadriceps were contracted 1) 4 knees (7.4%) with a normal patellofemoral alignment when the quadriceps were relaxed (Fig. 3A) showed Type II malalignment (Fig. 3B); 2) 18 knees (33.3%) showed a more pronounced lateralized or tilted patella (Fig. 4) with the same type of malalignment; 3) 6 knees (11.1%) changed the type of malalignment: 2 knees from Type I to II, 2 knees from Type III to II, and 2 knees from Type II to normal (Fig. 5).

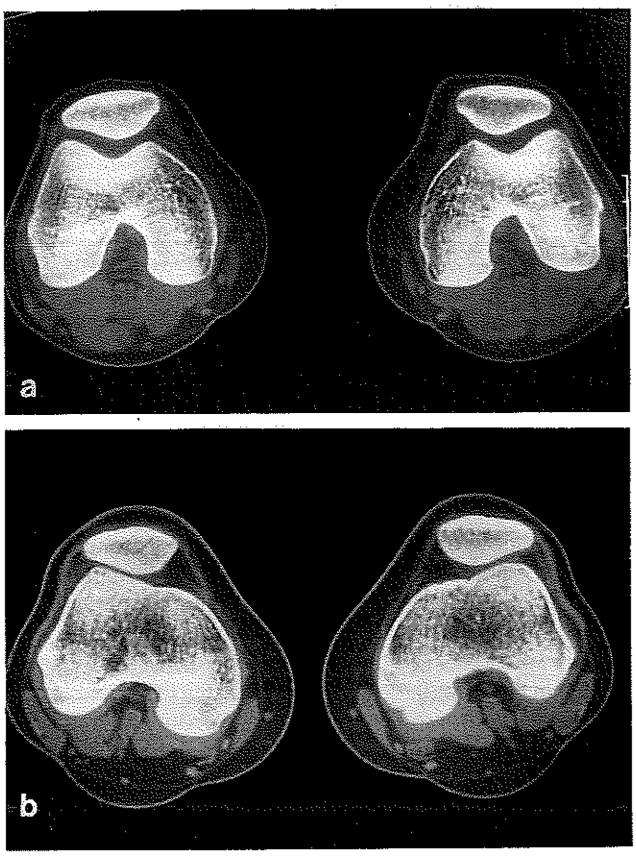

**Figure 3.** A 14-year-old patient with anterior knee pain without patellar instability. A, CT assessment with quadriceps relaxed; CA and PTA values are in the range of normal alignment. B, CT assessment with quadriceps contracted; Type II malalignment.

In patients with anterior knee pain and patellar instability, malalignment was more pronounced than in patients with anterior knee pain without instability. This difference was statistically significant for CA, PTA, CAc, PTAc, and TD (Table 4).

## DISCUSSION

The greater sensitivity and specificity of CT as compared with conventional radiographic methods in the diagnosis of patellofemoral malalignment have been demonstrated by

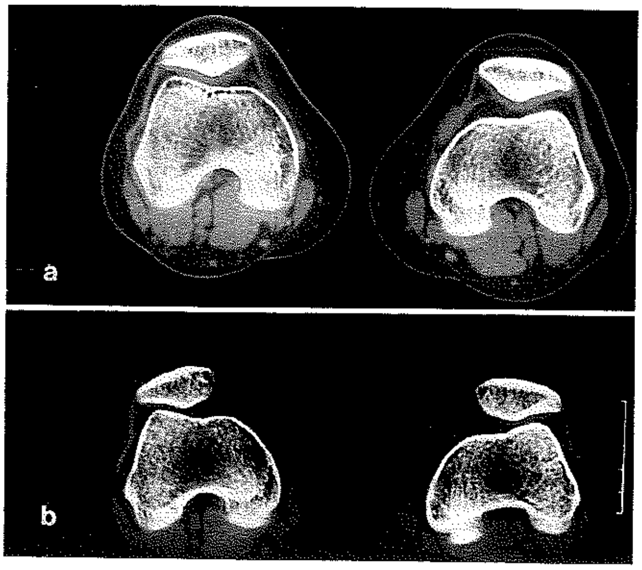

**Figure 4.** A 15-year-old patient with anterior knee pain and patellar instability. A, CT assessment with quadriceps relaxed. B, CT assessment with quadriceps contracted. There is a bilateral increase of patellar lateralization and tilting with quadriceps contraction.

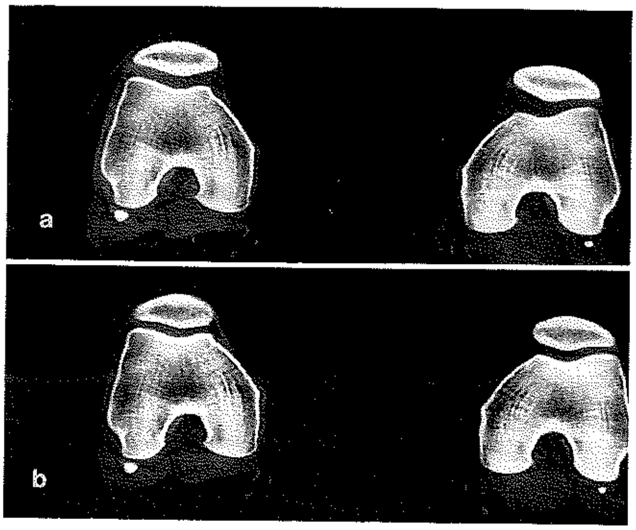

**Figure 5.** A 13-year-old patient with a left symptomatic knee (anterior knee pain without patellar instability). A, CT assessment with quadriceps relaxed; left lateralized and tilted patella. B, CT assessment with quadriceps contracted shows the tendency to restore normal patellar alignment.

numerous authors.[1–3,13,17,21,22] Nevertheless, some controversial aspects of the use of this method for studying patients with anterior knee pain still need to be clarified.

Our results show that there is a relationship between clinical findings and CT data. In patients with anterior knee pain and patellar instability, patellofemoral malalignment revealed by CT was, on average, more severe than in patients with anterior knee pain without instability (Table 4). Moreover, in agreement with Kuiala et al.,[14]

TABLE 4
CT parameters in symptomatic knees with pain or pain + instability (mean ± SD)[a]

| | Pain (14 knees) | Pain + instability (13 knees) |
|---|---|---|
| CA | 5.9 (16)[a] | 25.8 (21)[a] |
| PTA | 8.9 (9)[b] | 0.9 (10.4)[b] |
| CAc | 13.8 (19)[a] | 37.8 (19)[a] |
| PTAc | 9.5 (9)[b] | −1.0 (11)[b] |
| SA | 144 (6) NS | 150 (13) NS |
| TD | 8.1 (2)[b] | 5.3 (3)[b] |

[a] See footnote at Table 2 for statistical description.

we observed a significant difference in CA, PTA, CAc, and PTAc of the symptomatic knee as compared with the contralateral knee. However, SA and TD values were not significantly different in the symptomatic and contralateral knees (Table 3).

Fulkerson and Shea[9] recently suggested that the type of malalignment could be a determinant factor in the choice of an optimal made-to-measure treatment. Computerized tomographic assessment with the quadriceps relaxed permitted us to divide the knees into three types of patellofemoral malalignment (Fig. 2): 44.4% were Type II, 24.1% were Type I, and 22.2% were Type III. In Type II we observed a shallower femoral trochlea than in Types I and III (with a higher SA and lower TD). These results in adolescent patients confirm the findings of Schutzer et al.[21] in patients between 17 and 40 years.

In a CT and magnetic resonance imaging assessment, Kuiala et al.[14] revealed only Type II malalignment. The absence of Types I and III in their study could perhaps be explained by the fact that all of their patients had recurrent patellar dislocation, a factor that was excluded from our study.

To our knowledge, not many studies have been performed with *quadriceps contracted*, and the results are discordant.[7,17,20,21] Martinez et al.[17] were the first authors to use this kind of assessment in patients with patellofemoral syndrome, but the limited number of patients did not permit them to assess the effects of quadriceps contraction. Schutzer et al.[21] performed CT examinations with quadriceps contracted and observed that maximum quadriceps contraction with the knee flexed to 15° did not produce a consistent or significant effect on patellar tracking. However, Sasaki and Yagi[20] and Fernandez de Rota et al.[7] reported an increase in lateralization and patellar tilt with quadriceps contracted. Moreover, Sasaki and Yagi maintained that quadriceps contraction during CT imaging substitutes for tension of the quadriceps muscle during loadbearing.

Dowd and Bentley[6] claimed that patellar instability is a dynamic phenomenon that can also be related to alterations of muscular function; therefore, it cannot always be identified with radiographic methods in a static situation. Recently, Voight and Wieder[25] confirmed that muscular control imbalance may cause or contribute to anterior knee pain in young patients.

In the present study, in 48.2% of knees there were no differences between CT assessment with quadriceps relaxed and with quadriceps contracted in either type or severity of malalignment. On the contrary, in the remaining 51.8% of symptomatic knees we found, in two patients with apparently normal patellofemoral alignment when quadriceps were relaxed, bilateral Type II malalignment when quadriceps were contracted (Fig. 3). Therefore, this would suggest that some otherwise unrecognized malalignments can be revealed when quadriceps are contracted.

Also, in 18 knees we found that the type of malalignment remained unchanged, but that lateralization and tilting of the patella were markedly more severe when quadriceps were contracted (Fig. 4). In another four knees we found that Type I or III malalignment with quadriceps relaxed was Type II with quadriceps contracted. Hence, it is possible to identify those malalignments that worsen during muscular activity. In these cases, lateral retinacular release alone may not be sufficient to rectify patellofemoral malalignment and proximal or distal realignment must be considered. In two knees in our study, muscle activity reduced the patellar lateralization and tilting (Fig. 5) observed with the quadriceps relaxed by shifting the patella medially. The CT assessment with the quadriceps contracted thus makes it possible to foresee the risk of medial patellar subluxation after lateral retinacular release.[9,12,23]

In conclusion, before planning an operation in patients with anterior knee pain with or without patellar instability, CT assessment both with quadriceps relaxed and with quadriceps contracted permits a reliable documentation of malalignment. In fact, CT assessment with quadriceps contracted may evidence a different type of malalignment or reveal the aggravation or improvement of malalignment as compared with CT assessment with quadriceps relaxed. Because some authors suggest that the type of operation should be selected on the basis of the type and severity of malalignment,[9,21,22] we believe that CT assessment with quadriceps contraction might be a useful adjunct in permitting the surgeon to select the optimal treatment. However, further studies are necessary to establish the real advantage of this method in the choice of the best treatment for the individual patient and in the evaluation of the postoperative results.

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