Patellofemoral instability: classification and imaging

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Abstract

Patellofemoral disorders must be approached through an appropriate process of diagnostic framing, performed using language that is, as far as possible, unequivocal and a validated and organic classification system. At present, the classification proposed by the Lyonnaise school, which fulfills these requirements, is the most complete. This classification divides patellofemoral disorders into three groups: objective patellar instability, potential patellar instability and painful patella syndrome. It also identifies three principal factors of instability: trochlear dysplasia, abnormal patellar height and pathological tibial tubercle-trochlear groove (TT-TG) distance. Imaging is crucial for correct classification and for identifying and measuring the principal factors of instability. Up to now, the emphasis has been placed on the contribution made by traditional diagnostic radiology and computed tomography.

In recent years, however, growing attention has been paid to the use of magnetic resonance imaging in the assessment of the patellofemoral joint and in the study of factors of instability, even though there is still a need for validation of this approach before it can be routinely used in preoperative planning.

Key Words: classification, imaging, patellar instability, patellofemoral, TT-TG.

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Introduction

Patellofemoral disorders must be approached through a correct process of diagnostic framing, performed using language that is, as far as possible, unequivocal. First of all, reference must be made to a validated and organic classification system.

The Lyonnaise school, over the years, has perfected a simple and organic sytem for classifying patellofemoral pathology and this classification is now internationally recognized (1).

Classification of patellofemoral disorders

Patellofemoral disorders can be divided into three main groups:

- **Objective patellar instability**
- **Potential patellar instability**
- **Patellofemoral pain**

Objective patellar instability
This group includes patients who, in the course of their life, have experienced at least one episode of patellar dislocation or subluxation and who present at least one of the principal factors of instability. This category also includes patients with severe patellar instability (recurrent or permanent dislocations).

Potential patellar instability
Patients classified in this group have never experienced a dislocation or subluxation; their main symptom is pain and they present one or more of the principal factors of instability.

Patellofemoral pain
Pain is main symptom presented by patients classified in this group, in whom none of the principal factors of instability can be identified.

The principal factors of instability

There are three principal factors of instability, occurring in the following order of frequency:
• **Trochlear dysplasia**
• **Abnormal patellar height**
• **Pathological tibial tubercle-trochlear groove (TT-TG) distance.**
Trochlear dysplasia, of varying degrees, is present in 96% of cases of objective or potential patellar instability. *Abnormal patellar height* and *pathological TT-TG distance* have an incidence of between 30% and 83%. Until a few years ago, *patellar tilt* was also considered a principal factor of instability. Today, however, it is considered an associated factor, as it is present in more than 85% of cases in which one or more of the main factors of instability can be detected.

Secondary factors of instability

In addition to the principal factors there are also secondary factors of instability, namely:
• **varus/valgus malalignment**
• **genu recurvatum**
• **pathological (femoral/tibial) torsion angle**
• **patellar dysplasia**
• **abnormal pronation of the subtalar joint**
The principal factors of instability can be detected with extreme precision through an accurate instrumental evaluation, while the secondary ones can initially be classified clinically and then better defined through specific radiological or imaging investigations.

Radiographic evaluation of the patellofemoral joint

Of all the investigations thus far described and used to evaluate the patellofemoral joint, the *lateral view* can, today, be considered by far the most useful for detecting trochlear dysplasia, in association with computed tomograhy (CT), and abnormal patellar height.
Axial view of the patella with the knee in 20° of flex-

ion allows us to detect striking cases of patellar tilt. *Teleradiography with one or both feet in weight-bearing position* can be used to accurately calculate the extent of an axial deviation of the knee.

Radiographic classification of trochlear dysplasia, according to the Lyonnaise School, is based on observation of the trochlea on a lateral knee X-ray, which must be performed with the condyles perfectly superimposed. A CT scan is also performed.
On the basis of different findings, it is possible to distinguish four types of trochlear dysplasia:
• *Type A*: on lateral X-ray radiographs, the line of the trochlear groove is seen to intersect the anterior border of one of the condyles ("crossing sign"), while on CT images the trochlea appears practically normal (**Fig. 1A**).
• *Type B*: on lateral X-ray radiographs, it is possible to see the so-called supratrochlear spur. On CT images the trochlea is starting to assume a convex shape (**Fig. 1B**).
• *Type C:* on lateral X-ray radiographs, it is possible to observe a "double contour" which represents a neo-articulation formed between the patella and a severely dysplasic trochlea, while on CT images the trochlea appears flattened (**Fig. 1C**).
• *Type D*: on lateral X-ray radiographs, all three signs of dysplasia are present ("crossing sign", double contour and spur), while on CT images the trochlea is shaped like a camel's hump.
Type C and D trochlear dysplasias are the most severe, and in the presence of objective instability warrant surgical correction (**Fig. 1D**).
Various indices for studying and measuring *patellar height* have been described in the literature (2-4). The Caton-Deschamps index is the most reliable, as it is the one least influenced by the degree of knee flexion. Its value represents the ratio of the distance between the lowest point of the articular surface of the patella and the tibial articular surface to the length of the entire articular surface of the patella (i.e. excluding the apex) (**Fig. 2**). Patellar height is considered pathological when this ratio is greater than 1.2. In these cases, an operation is needed to lower the patella.
Axial projections with the knee in 20° of flexion can instead, using the parameters of Laurin et al. (5), reveal the presence of patellar tilt. These authors define the tilt angle as the angle between a line traced between the summits of the two trochlear slopes and a line tangent to the lateral facet of the patella. This angle is normal if it is
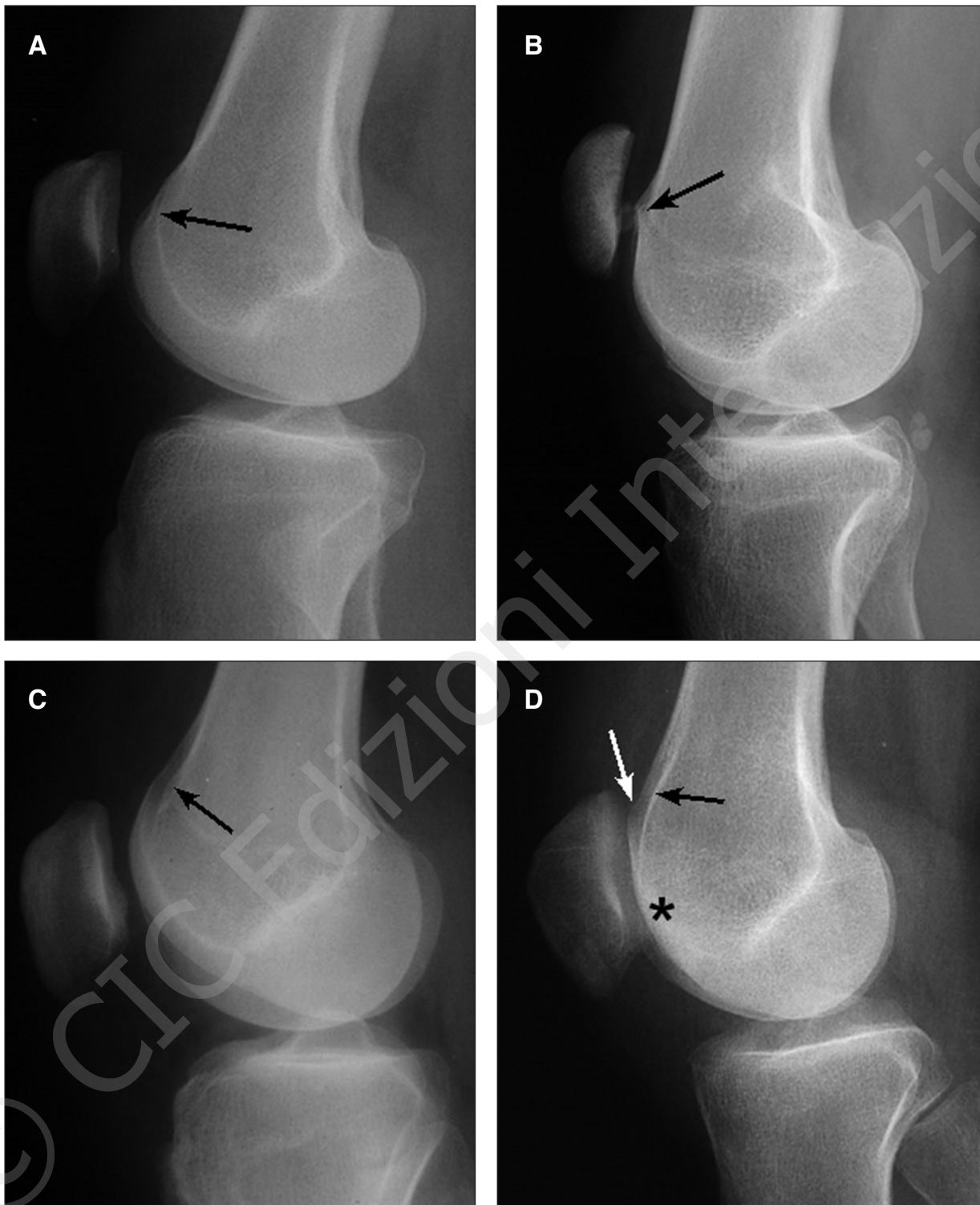
Fig. 1. Classification of trochlear dysplasia. A: Grade A dysplasia. The "crossing sign" (arrow) is evident. B: Grade B dysplasia. Evidence of crossing sign and supratrochlear spur (arrow). C: Grade C dysplasia. Evidence of crossing sign and double contour (arrow). D: Grade D dysplasia. Concomitant presence of crossing sign (asterisk), supratrochlear spur (white arrow) and double contour (black arrow).
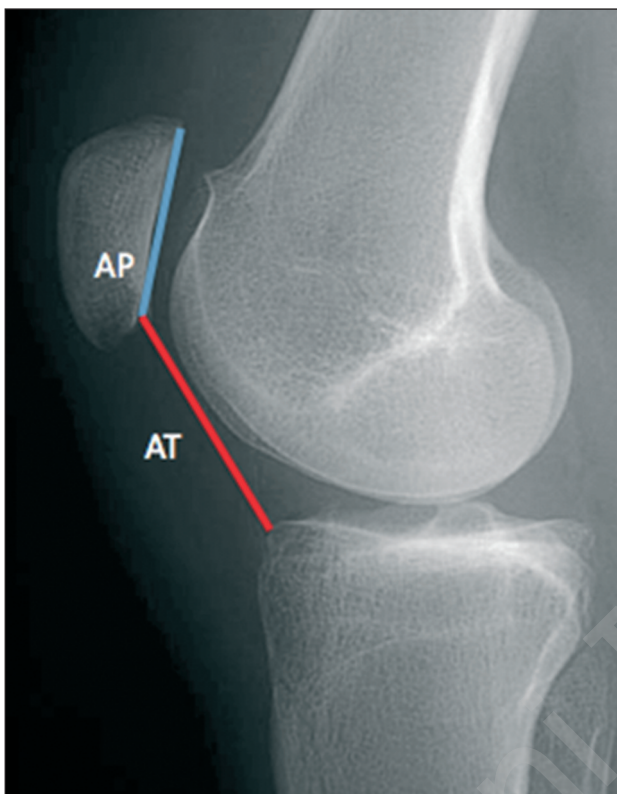
Fig. 2. Caton-Deschamps Index. Its value represents the ratio of the distance between the lowest point of the articular surface of the patella and the tibial articular surface (AT) to the length of the entire articular surface of the patella (AP). The cutoff value to define patella alta is 1.2.

open laterally, borderline if the two lines are parallel, but definitely pathological if it opens medially. This evaluation should, however, be complemented by a CT scan.

Computed tomography

CT is still considered very useful in defining certain pathological values of the patellofemoral joint, in particular:

- *the TT-TG value*
- *patellar tilt*
- *femoral and tibial torsion angles.*

The **TT-TG** is the distance in mm between the tibial tuberosity and the deepest point of the trochlear groove (6). It expresses, as a linear measurement, the Q angle. For years, a TT-TG of 15 mm was considered the threshold limit. Today, a TT-TG greater than 20 mm is considered pathological and therefore to warrant correction.

Patellar tilt, which is calculated on an axial CT scan

with the quadriceps relaxed and contracted, is the measure of the angle formed at the intersection between the major axis of the patella and the line connecting the two most posterior points of the femoral condyles (7). The mean of the values measured in the two conditions (relaxed and contracted) is considered pathological if it exceeds 20 degrees, as this is an indication of medial patellofemoral ligament insufficiency.

Femoral torsion is the measure of the angle formed between a line running through the center of the femoral head and the center of the femoral neck at its junction with the diaphysis and the posterior bicondylar line. The mean value of this angle measured using these landmarks is 13 degrees of femoral anteversion.

Tibial torsion is measured between the knee flexion-extension axis and the ankle joint axis. Since the reproducibility of the measurement at tibial level is uncertain, femoral references, such as the transepicondylar axis or the posterior bicondylar line, are often used. Mean values (30-35 degrees) show considerable gender- and ethnic-related variability.

The role of magnetic resonance imaging

Magnetic resonance imaging (MRI), providing thinner and higher-resolution scans, allows a more accurate study of the patellofemoral joint cartilage surface than CT does. Furthermore, it does not involve the use of ionizing radiation, and also allows measurements to be taken at the level of the cartilage rather than only at that of the subchondral bone (as in conventional radiology).

Even though the literature supports the use of MRI in the development of methods for measuring patellofemoral joint abnormalities, there are, as yet, no published studies defining and validating normal and pathological MRI parameters that can be used for assessing these abnormalities in clinical routine.

Let us then analyze briefly the current role of MRI in the analysis of the principal factors of instability considered above:

Trochlear dysplasia

Carrillon et al. (8) measured the lateral trochlear inclination (LTI) angle on MRI scans in 30 patients with patellar instability and in a control group of 30 patients without patellar instability and compared the results in order to establish the reliability of this index, which was first described by Bernageau et al. (9) as a radiographic measure of trochlear dysplasia. The MRI was per-

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formed on the knee in full extension using T2-weighted fat-suppressed turbo spin-echo sequences. The measurement was performed on the first craniocaudal image on which the trochlear cartilage could be seen (**Fig. 3**). The LTI was calculated by considering a line tangent to the subchondral bone of the posterior aspect of the femoral condyles, and measuring the angle formed between this line and line tangent to the subchondal bone of the lateral lateral facet of the trochlea. A statistically significant difference was found between the two groups, with the patellar instability patients recording a mean value of 6.17° and the control group 16.93°. Taking 11° as the LTI threshold value, this index was found to give excellent results, discriminating between the two groups with a sensitivity of 93%, a specificity of 87% and an accuracy of 90%.

Keser et al. (10), also using 11° as the cut-off value for trochlear dysplasia, examined 104 patients with anterior knee pain (109 knees in all) and a control group of 74 healthy knees. The measurement was performed at the level of cartilage. The results showed no significant differences between males and females in either group. The mean LTI value was 21.5° in the group with anterior knee pain and 17.5° in the control group. Of the patients with anterior pain, 16.5% had an LTI angle value greater than 11° as compared with just 2.7% in the control group. 77.7% of the patients with trochlear dysplasia had associated patellar tilt.

These studies, considering two different conditions (instability and pain), seem to indicate that pathological LTI values range from 6.2° to 21.5°. Future studies may help to validate an LTI angle value of 11° as an adequate MRI parameter for measuring the extent of trochlear dysplasia.

TT-TG

Schoettle et al. (11) compared the TT-TG values recorded on CT and MRI scans in 12 knees (11 patients), most of which (n=10) showed patellar instability. The measurements were performed using both bony and catilaginous trochlear groove landmarks. The mean TT-TG value calculated using bony landmarks was 14.4 mm on CT, versus 13.9 mm on MRI scans. A significant difference emerged between the values calculated using cartilaginous landmarks: 15.3 mm on CT versus 13.5 mm on MRI scans. The study showed an intermethod reliability of 86% (**Fig. 4**).

The significant difference found when using the cartilaginous landmarks seems to confirm that this approach is more reasonable on MRI scans, given that the cartilage surface is where the forces, at patellofemoral joint level, are actually exerted. The main problem appears to be that of identifying the point on the femur that allows a correct measurement to be obtained, in other words the deepest cartilaginous point of the most proximal portion of the entirely cartilage-covered trochlea. The use of a more distal point
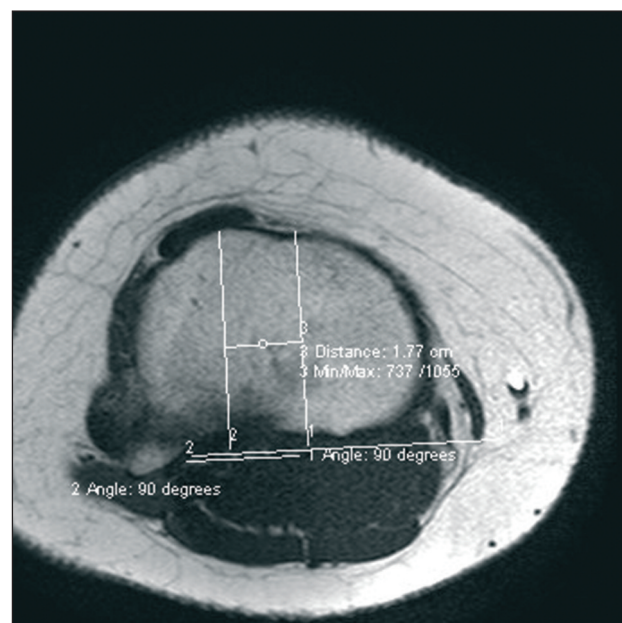

Fig. 3. Lateral Trochlear Index (LTI).

Fig. 4. Measurement of TT-TG on MRI scan.

11

would result in a lower TT-TG value as the trochlear groove deviates medially at its distal part.

Another study also used MRI in the evaluation of TT-TG, but used different methods for acquiring and measuring parameters (12). Fourteen healthy subjects and 14 patients complaining mainly of anterior knee pain were examined. All the patients underwent MRI and axial X-ray with the knee flexed to 30°. Four MR slices were acquired and considered: the first axial slice corresponded to the level of the distal femur at the point where the anteroposterior diameter of the condyles is greatest. At this level, three lines were drawn, two tangent to the posterior and anterior aspects of the femoral condyles and the third perpendicular to the posterior bicondylar line passing through the apex of the femoral trochlea.

The second axial slice of the distal femur corresponded to the level of greatest patellar transverse diameter. At this level a line was traced connecting the apex of the patella and the external border of the lateral facet. This line and the one tangent to the anterior aspect of the femoral condyles (traced previously) were used to determine the lateral patellofemoral angle.

The third axial slice corresponded to the level of patellar tendon insertion at the anterior tibial tuberosity (ATT). The distance between the line traced at this level, passing through the middle of the tendon insertion, and the one traced on the first slice passing through the trochlea constituted TT-TG distance as measured using MRI.

Patellar height was then measured on a fourth slice (sagittal) using the Insall-Salvati method. To evaluate the sensitivity and specificity of MRI measurements, threshold values of 10 mm for the TT-TG and 8° for the lateral patellofemoral angle were chosen.

The TT-TG value was found to be greater (12.6 mm) in the symptomatic patients than in the control group (9.4 mm), while the lateral patellofemoral angle was smaller (2.56°). The Insall-Salvati index was higher in the symptomatic patients (1.17 versus 1.02), who also showed a higher incidence of patella alta (index > 1.2). Taking 10 mm as the TT-TG threshold value, deviation of the ATT was specific for anterior pain in 70% and sensitive in 64%. Nine of the 14 patients had a TT-TG value greater than 10 mm and a lateral patellofemoral angle of less than 8°, while four patients with an angle greater than 8° had a normal TT-TG distance. This study confirmed that reproducible measurements of the TT-TG can be obtained using MRI. The weaknesses of the study were its design (it was a single-blind case-control study with uneven gender distribution in the two groups) and the measurement method, which did not take the shape of the trochlear groove into account. In these studies, which considered two different conditions (pain and instability), the pathological value of the TT-TG was found to range between 12.6 and 13.5 mm.

Patellar tilt

Various methods for measuring patellar tilt have been proposed in different studies (13-16), giving very different values, considered by the authors to predict of the level of insertion of the vastus medialis, pain and anterior patellar instability. However, the assessment methods used were very different, they were applied in very small samples, and contraction of the quadriceps was never taken into consideration.

Grelsamer et al. (13) used the Powers and Nove-Josserand method to measure the patellar tilt angle on MRI in 81 patients (30 with anterior pain and clinical evidence of patellar tilt and 51 with anterior pain but no clinical evidence of tilt). The images were acquired with the knee flexed to 10° and the quadriceps relaxed and the angle was determined using bony rather than cartilaginous landmarks. All the patients who presented patellar tilt had a lateral patellofemoral angle greater than 10° (*versus* 22% in the control group). The mean angle value was 18° ± 7° in the patients *versus* 6° ± 5° in the control group. The authors found overall agreement between radiographic assessment and clinical examination in 88%. The weaknesses of this study were the absence of quadriceps contraction and the use of bony rather than cartilaginous landmarks for measurement.

At present, too many factors influence MRI-based determination of patellar tilt.

Consequently, more homogeneous studies need to be performed in order to validate measurements of patellar tilt obtained using MRI.

Patella alta

Many studies have investigated the use of MRI in the measurement of patellar height. Miller et al. (17) found a good correlation between MRI and X-ray findings, all obtained using the Insall-Salvati index. According to the authors, a value of 1.3 is the diagnostic threshold beyond which a subject has patella alta. No significant differences were found between males and females and the ratio was not influenced by wrinkling of the patellar tendon.

Instead, the criteria established by Shabshin et al. (18), in a retrospective analysis of 245 patients, were 0.74 for patella baja and 1.5 for patella alta.

The possible relevance of patellar tendon length in determining patellar height was highlighted by Neyret et al. (19) They compared two groups of patients (instability and controls), evaluated with X-rays and MRI, in whom the following parameters were investigated: patellar height determined using the Caton-Deschamps index, patellar tendon length and ATT height. This latter parameter was similar in the two groups (28 vs 29 mm). Conversely, the mean patellar tendon length was found to be 53 mm in the instability group *versus* 46 mm in the controls. The correlation between the Caton-Deschamps index measured on MRI and on traditional X-ray was excellent in both groups, although MRI showed greater sensitivity in detecting a pathological value (60% versus 48% with traditional X-ray). This study supports the hypothesis that patella alta can be caused by a long patellar tendon rather than by a more distal insertion of the tendon into the tibia and that, therefore, in these cases tenodesis of the patellar tendon may be indicated. However, more studies are needed, possibly conducted using measurements taken using cartilaginous references, in order to define an index of patellar height that is reproducible on MRI, and to investigate the role of patellar tendon length in the etiology of patella alta.

Conclusions

Traditional X-rays are still fundamental in classifying and measuring some of the principal and secondary factors of instability. In particular, using lateral views, it is possible to identify four types of trochlear dysplasia and to measure patellar height.

Computed tomography can be used to measure the TT-TG length (pathological value=>20°), patellar tilt in the absence of vastus medialis contraction, and femoral and tibial torsion angles.

MRI, using thinner slices and without the need for ionizing radiation, can show, with a higher resolution than CT, the cartilaginous patellofemoral joint surface, and also allows measurements to be taken at cartilage level and not only at the level of the subchondral bone, as in conventional radiology.

Because of poor correspondence between the cartilagi-

nous and bony anatomy, demonstrated by imaging studies on cadavers, angles measured on MRI scans using cartilaginous references are larger than those measured using bony references.

Trochlear dysplasia, evaluated on MRI scans, should be determined using the LTI index, which is derived from radiological measurements. Pathological LTI values recorded in studies published in the current literature, with reference to two conditions (instability and pain), range from 6.17 to 21.5°, with a threshold value of 11°. MRI measurements of the TT-TG distance seem to be more reliable if taken at the level of the cartilage, given that this is where the forces, at patellofemoral joint level, are actually exerted. Pathological TT-TG values measured on MRI scans range from 12.6 to 13.5 mm (in pain and instability), and differences versus values measured on CT are significant. The main problem appears to be that of identifying the TG landmark, which should correspond to the deepest cartilaginous point on the most proximal slice on which the cartilaginous trochlea can be seen. The use of a more distal slice would result in a lower TT-TG value because the trochlear groove deviates medially at its distal part.

Too many factors influence MRI-based determination of patellar tilt. Consequently, more homogeneous studies and assessment methods are needed to validate MRI as an instrument for defining patellar tilt.

Good agreement has been found between X-ray- and MRI-based measurements of patellar height, calculated using both the Insall-Salvati index and the Caton-Deschamps index. A ratio of 1.3 is considered the upper limit of normal when using MRI. It is also possible to determine the length of the patellar tendon, whose mean value has been found to be 53 mm in patients with instability and 46 mm in healthy subjects.

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