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An anatomical and radiological study of the femoropatellar articulation

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Summary. An analytical study was made of 30 knees by dissection, 200 by conventional radiology, 120 by CT scans, and of 2,400 pathological knees by conventional radiology, and 900 by CT. The radiological and scanning methods most used for a study of the femoropatellar articulation are described and the normal values of each feature determined by a computer study. The femoral trochlea and its shape are very important for the stability of the patella. The normal and pathological types of trochlea are described. This study established a number of anatomical factors which influence patellar stability, and form a basis for proposing the correction of anatomical anomalies in the treatment of instability of the joint.

Etude radio-anatomique de l'articulation fémoro-patellaire

Résumé. Les auteurs ont analysé 30 genoux par dissection, une série en radiologie conventionnelle de 200 genoux témoins, une série de 120 tomodensitométries de genoux témoins, une population pathologique de 2 400 genoux en radiologie conventionnelle et de 900 genoux en tomodensitométrie. Les méthodes radiologiques et scannographiques les plus utiles pour analyser l'articulation fémoro-patellaire sont décrites et les valeurs normales de chaque facteur précisées à partir d'une étude informatique. La trochlée fémorale et sa morphologie sont très importantes pour stabiliser la rotule. Des types de trochlées normales et pathologiques sont décrits. Cette étude permet d'établir un certain nombre de facteurs anatomiques influençant la stabilité patellaire et, en s'appuyant sur une étude parallèle, de proposer la correction des anomalies anatomiques dans le traitement des instabilités patellaires.

Key words : Patella — Trochlea — Dysplasia

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Because of the frequency of femoropatellar pathology and the evidence that anatomical factors can be the cause of patellar instability and of painful patellar syndromes, we have carried out an anatomical and radiological analysis of this joint.

Method and material

Method

The joint has been studied by dissection and anatomical cuts, by standard radiology, and by scanner.

The dissection and cuts were of freshly frozen subjects. The cuts were in the sagittal and horizontal planes, the knee being in 30° of flexion.

The standard radiographs comprised one lateral view with the knee in 30° of flexion, and an axial view of the patella:

- the profile radiograph was strictly lateral, with the posterior borders of the two condyles superimposed and the central ray along the articular line;
- the axial view of the patella was with the knee in 30° of flexion. For this view the leg and foot were rotated to the angle of step determined before the examination.

The scanner: the patient was placed supine, the feet externally rotated 15° on a board perpendicular

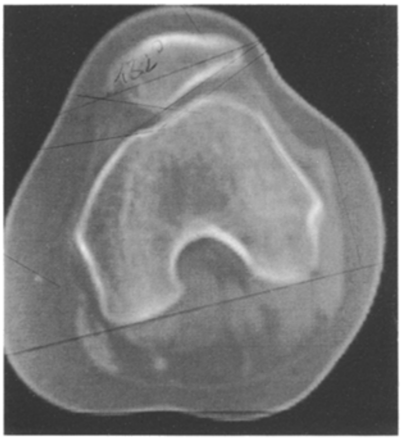


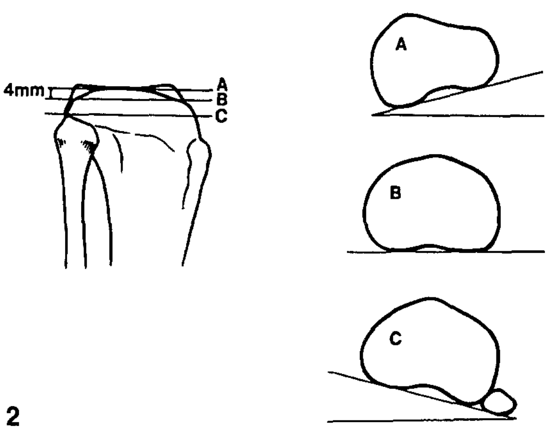
Fig. 1
CT through femoral condyle. The intercondylar notch has the form of a roman arch

Coupe tomodensitométrique du condyle fémoral. L'échancrure intercondylienne a la forme d'un arc roman

to the table, in such a way as to avoid movement during the examination. Lerat [10] recommended placing the feet in the angle of step. We have compared scan cuts in neutral position and with external and internal rotation and have found that the measurements are not affected by these different positions. The plantar support is necessary to avoid quadriceps contraction. The examination was carried out twice: static and then dynamic.

The static examination was always carried out first because the maneuvers required for the dynamic study change the position of the limb. It comprised: (1) a cut at the level of the hip, passing through the top of the digital fossa. Although Lerat [10] recommended making two cuts (through the femoral head and the base of the neck), it appears that the error in the measurement of the axis of the neck is minimal. (2) A cut passing through the middle of the patella for an analysis of the trochlea. The study of various scanner cuts and of sections in the cadaver have enabled us to determine exactly the ideal cut: the best reference is the intercondylar notch which has different appearances according to the level. In the most distal part, the lateral surface of the intercondylar notch forms a vertical line and the medial surface forms a curve like a gothic arch. In the proximal part of the trochlea, the notch forms a rounded Roman arch. This is the landmark that one tries to show (Fig. 1). When the cut is too high, it has the form of an arc of a circle representing a quarter of a sphere and the condyles disappear. On the lateral surface the area of insertion of the popleteus muscle has disappeared. The trochlear angle is further changed, the lines which form this angle are no longer straight lines but curves, and we are below the trochlea. (3) A cut through the upper tibial epiphysis just below the articular plane allows one to determine the posterior axis of orientation of the tibial epiphysis. The main part of lateral tibial torsion is in the upper few centimeters of the superior epiphysis; the measurement should thus be made as high as possible in the tibia. The ideal cut has as its limits the tibiofibular articulation below and the beginning of the posterior vertical surface of the lateral tibial plateau above. This much reduced space explains the frequent errors in measuring the posterior tibial axis. This error is often of several degrees (Fig. 2). (4) A cut through the bimalleolar axis.

The dynamic examination is made with cuts through the middle



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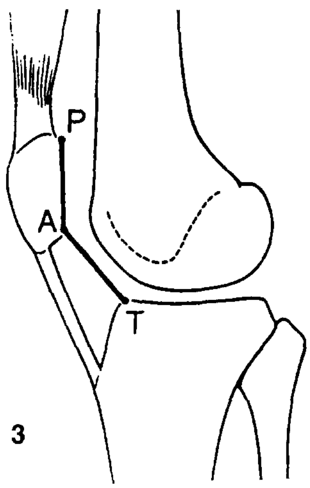

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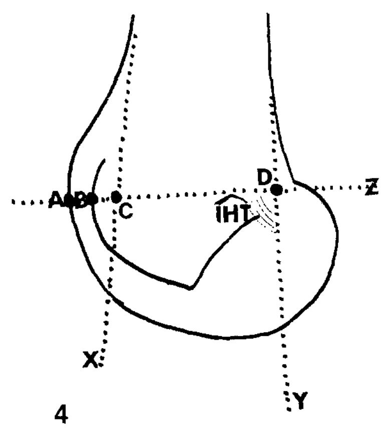

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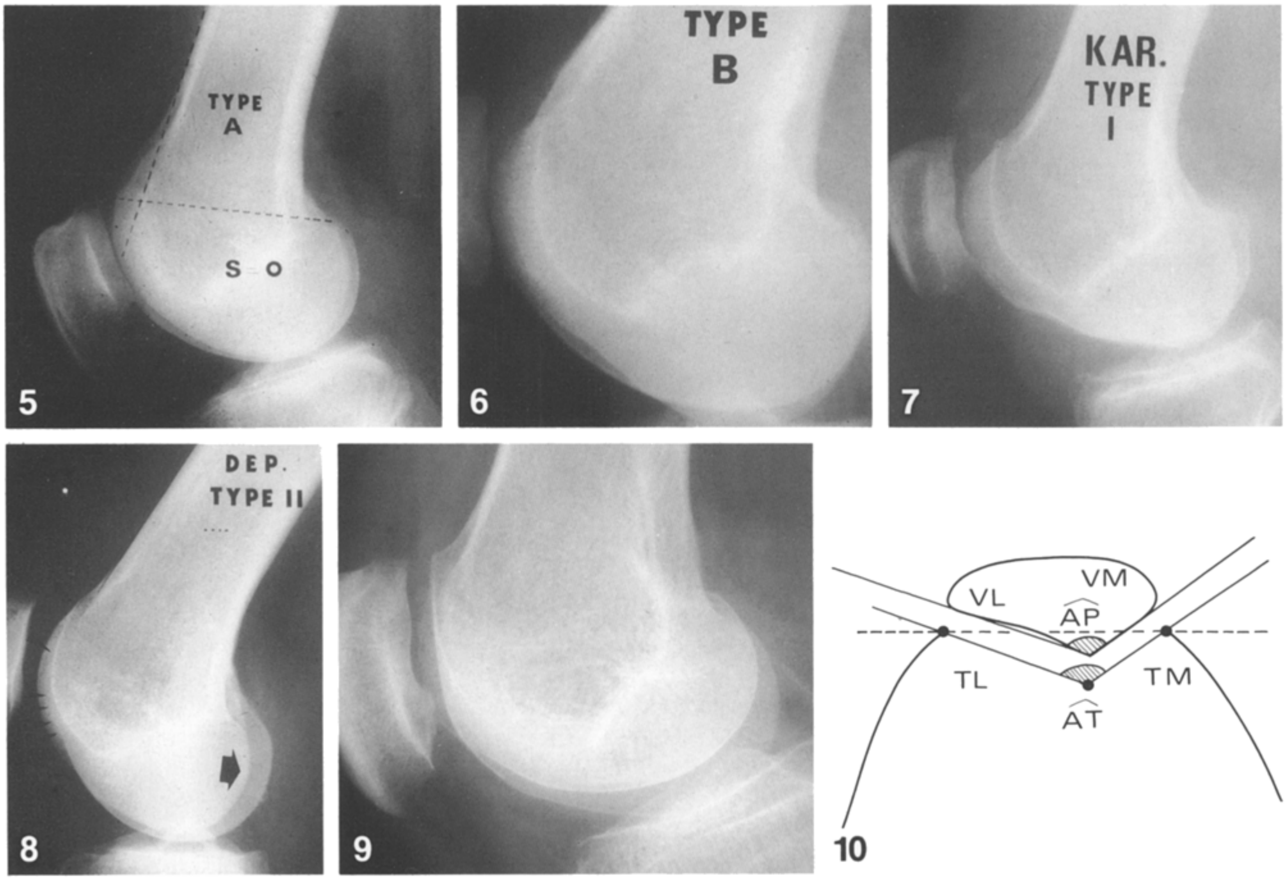
Figs. 2-4
2 Changes in the femorotibial rotation at different levels of the section. The ideal section is cut B **3** The measurement of patellar height according to Caton **4** The geometric construction for the analysis of the trochlea

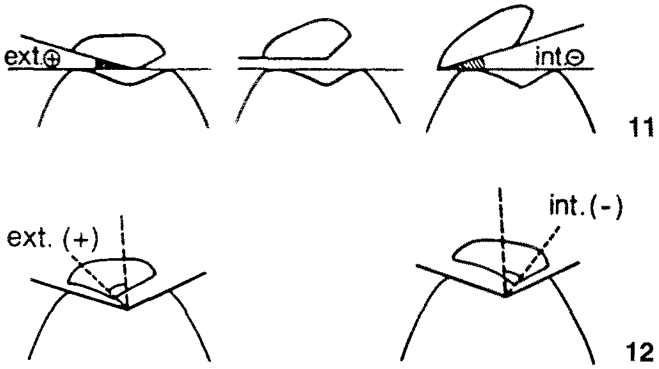
2 Variations de la rotation fémoro-tibiale selon le niveau des coupes. La coupe idéale est la coupe B **3** Mesure de la hauteur patellaire selon Caton **4** Construction géométrique nécessaire à l'analyse de la trochlée



Figs. 5-10

5 Trochlea type A; the lines of the intercondylar groove and the condyles do not cross **6** Type B; only the medial condyle crosses the line of the intercondylar groove **7** Type I. The crossing is at the upper part of the trochlea **8** Type II. Asymmetrical crossing of the intercondylar groove and the medial and lateral condyles **9** Type III. A very low crossing of the two condyles. The trochlea is very flat **10** The positions of the trochlear angle AT and the patellar angle AP, in relation to the trochlear slopes TL/TM and the patellar slopes VL/VM

5 Type A de trochlée, il n'existe pas de croisement entre la ligne de fond de la trochlée et les condyles **6** Type B, le condyle médial croise de façon isolée la ligne de fond de la trochlée **7** Type I. Le croisement se fait à la partie haute de la trochlée **8** Type II. Asymétrie de croisement entre le fond de la trochlée et les condyles médial et latéral **9** Type III. Croisement des deux condyles très bas. La trochlée est plate **10** Mise en place de l'angle trochléen AT de l'angle patellaire AP, du rapport des pentes trochléennes TL/TM, du rapport des versants patellaires VL/VM



Figs. 11, 12

11 The patellar tilt, after Laurin **12** Patellar subluxation, after Merchant

11 La bascule patellaire selon Laurin **12** La subluxation patellaire selon Merchant

of the patella, and comprise: a scan in extension, with quadriceps contracted and a scan with 15° of flexion without contraction of the muscle.

Material

The anatomical studies by dissection and sections were carried out on 30 knees.

The radiological studies were on 200 knees free of any pathology, and 2400 knees with patellar pathology (instability or painful patellar syndrome).

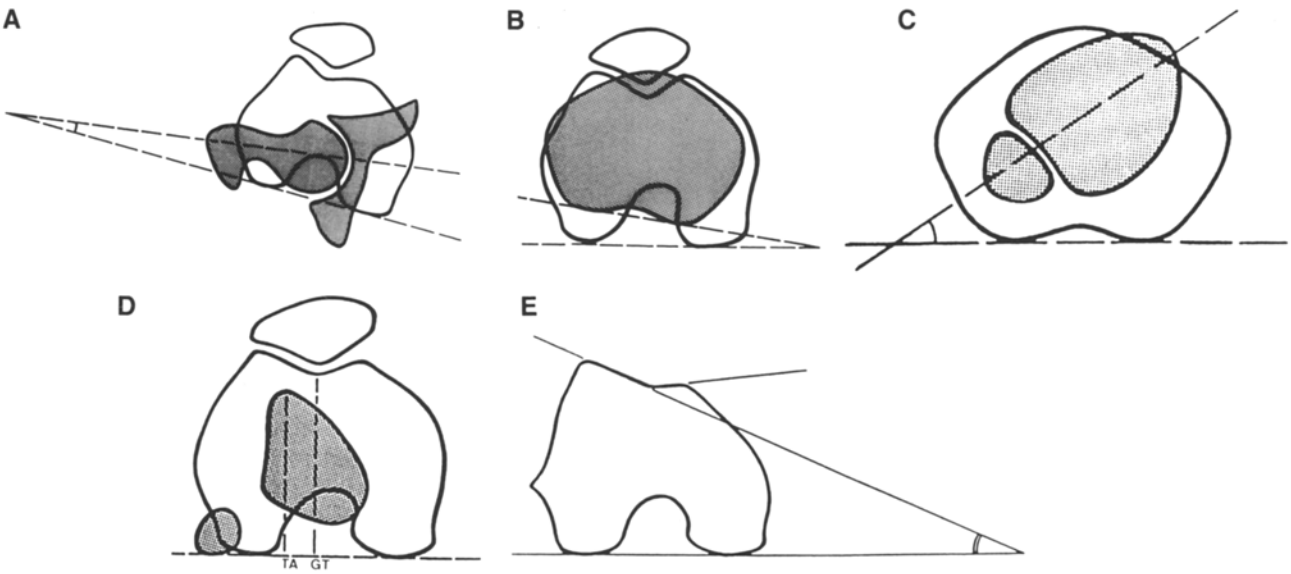


Fig. 13
A Measurement of femoral anterversion **B** measurement of rotation at the knee **C** measurement of lateral tibial torsion **D** measurement of TA-GT **E** measurement of the slope of the lateral facet of the trochlea

A Mesure de l'antéversion fémorale **B** mesure de la rotation dans le genou **C** mesure de la torsion tibiale latérale **D** mesure de la TA-GT **E** mesure de la pente du versant latéral de la trochlée

The CT studies were made on 120 normal knees and 900 knees with pathology (instability or painful patellar syndrome). All the results were computerised and statistically analysed to determine mean values, ranges and confidence intervals. These allowed the determination of abnormal values with a significance of $p < 0.001$.

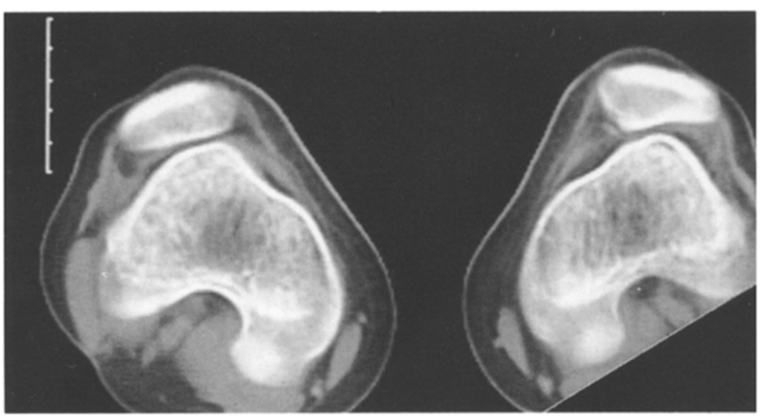


Fig. 14
Major patellar tilt, evidence of dysplasia of the m. vastus internus

Bascule patellaire majeure témoin d'une dysplasie du m. vaste médial

Results

A. The study by conventional radiology

The lateral radiographs provide measurement of some parameters regarding patellar height and the femoral trochlea.

The patellar height can be calculated with the help of a numerical index, such as those cited by Install and Salvetti [8] and Blackburne and Peel [2]. We have used the index of Caton [4] which is the ratio of the distance from the lower edge of the articular surface of the patella to the anterosuperior angle of the tibial outline (AT), to the length of the articular surface of the patella (AP). In our series this ratio was 0.95 (mean), SD 0.14. When the index is above 1.2 one may speak of patella alta, while an index below 0.8 indicates patella infera (Fig. 3).

The femoral trochlea has been particularly studied by Brattstrom [3] and by Maldague and Malghem [12]. In order to appreciate the morphology of the trochlea on a lateral radiograph, one must acquire the habit of defining 3 curves in the anterior part of the inferior epiphysis of the femur: the most anterior two curves correspond to the contours of the condyles, these may be superimposed or double; the curve immediately behind these corresponds to the intercondylar groove; it is the area which articulates with the median crest of the patella during the movements of extension and flexion. This line is the anterior prolongation of the line which represents the intercondylar notch. This outline of the intercondylar groove is concave anteriorly and in its superior part has two possible ways of ending: usually it gradually disappears without ever reaching the condylar lines when curving forwards where it becomes vertical; in other cases it crosses the anterior condylar lines; it may cross one or both of these. For a proper analysis of the trochlea it is advisable to make the following geometrical construction (Fig. 4); 3 lines are drawn: a vertical line X which is tangential to the lower 6 cm of the anterior cortex of the femur, a vertical line Y tangential to the lower 6 cm of the posterior cortex of the femur, a horizontal line Z which passes through the most anterior edge of the trochlea (point A) and through the superior edge of the femoral condyles posteriorly.

In this construction the point A corresponds to the most prominent part of the trochlea, the point B to the crossing of the horizontal line Z with the line of the intercondylar groove, the point C where the lines X and Z cross, the point D to where the lines Y and Z cross.

Several parameters may be defined:

- *the prominence of the trochlea,* which may be positive, negative, or nil. This corresponds to the distance between the most anterior point of the line of the intercondylar groove (point B) and the line of the anterior surface of the diaphysis (line X). This prominence on the above construction corresponds to the distance BC. It may be quantified in millimeters (distance BC), or in proportion to other measurements (BC×100/AD). If point B is anterior to point C one may speak of a positive prominence. If the points B and C coincide there is no prominence; if B is posterior to C there is negative prominence. The mean value in our series was 0.1 mm;
- *the depth of the trochlea* (Maldague [12]) corresponds to the distance AB. It is quantified in millimeters (distance AB) or in proportion to other individual parameters (AB×100/AD). Its mean value in our series was 4.3 mm;
- *the height of the trochlea.* We have tried to measure this by Raguet's method [14] by taking as the point of reference the most anterior point of the femoral condyles. This appears not to be statistically significant, particularly in the dysplasias. We have instead taken as the point of reference the most anterior point of the intercondylar groove (point B). On the schema we have described an angle formed by the lines Z and Y; this is the angle IHT in Fig. 4. In our series the mean of this angle was 74.4, SD 52, the range 70-87. The greater the dysplasia, the lower is the trochlea.

At the beginning of the study of the morphology of the trochlea and of the different parameters 2 types are generally encountered: the normal and the dysplastic.

The normal trochlea: by definition the line of the intercondylar groove never crosses that of the lateral condyle; 2 types of normal morphology of the medial condyle can be described A and B: in type A the two condyles are symmetrical, the line of the intercondylar groove never crosses that of the condyles (Fig. 5) and in type B the medial condyle crosses the line of the intercondylar groove after curving backwards (Fig. 6).

The dysplastic trochlea: this is associated in 98% of cases with patellar instability. The line of the intercondylar groove crosses both condyles.

According to the level of crossing, 3 types of trochlear dysplasia can be defined: I, II, III.

- *in type I* the two condyles are symmetrical and the line of the intercondylar groove crosses them at the same place in the upper part of the trochlea; this is the least marked degree of dysplasia (Fig. 7).
- *in type II* the condyles are asymmetrical. The medial condyle is dysplastic; it crosses the line of the intercondylar groove at a variable level. Then the line of the intercondylar groove is high and just crosses the lateral condyle (Fig. 8).
- *in type III* the condyles are symmetrical but the crossing is low, indicating an abnormally early formation of the trochlea, which is completely flat for a variable extent; this is marked dysplasia (Fig. 9).

The findings in the axial views have several parameters: the trochlear angle, the ratio TL/TM, the ratio VL/VM, the tilting and the subluxation of the patella.

The trochlear angle (AT, Fig. 10) is the angle formed by a line tangential to the lateral slope of the trochlea and a line tangential to the medial slope. The vertex of this angle corresponds to the groove of the trochlea. In our series it was 130°, SD 7°, with a range 112° to 146°. Ficat [5, 6, 7] considered an angle of 125° to be normal. Brattstrom [3] found the angle to vary between 141° and 143°.

The patellar angle (AP, Fig. 10) is formed by the two lines tangential to the lateral and medial slopes of the patella. A normal patella has an angle of 120° to 140°. Wiberg [15] described two types of dysplastic patella: the first is of a very flat patella with an angle greater than 140°; the second type has an angle less than 100° with a large lateral slope, almost the only articular surface, contrasting with the small medial slope.

The ratio of the trochlear slopes (TL/TM, Fig. 10) is the ratio of the widths of the two trochlear slopes. In our series its value was 1.4, SD 0.2, with a range of 0.7 to 2.

Trochlear dysplasia can be considered to be present when the ratio is above 1.7.

The ratio of the patellar slopes (VL/VM, Fig. 10) is the ratio of the width of the medial to that of the lateral slope of the patella (the patellar index). It is normally between 1 and 3.

The patellar tilt (Fig. 11) was studied by Laurin [9] who drew 2 lines, one joining the summits of the two trochlear slopes, the other tangential to the lateral slope of the patella. These lines form a positive angle open laterally, negative open medially, and nil when the two lines are parallel. A negative Laurin angle [9] means a lateral tilt and is therefore synonymous with patellar instability.

Patellar subluxation has been studied by the angle of congruence of Merchant [13] (Fig. 12). The bisector of the trochlear angle described above is drawn; a second line is drawn between the deepest point of the intercondylar groove and the most posterior point of the articular surface of the patella. These lines form the angle of congruence. If the patellar point is lateral to the bisector the angle is positive and the subluxation is also lateral. If the patellar point is medial to the bisector the angle is negative and the subluxation is medial.

B. The CT study

Some notions have followed from the findings derived from axial views of the patella, particularly the trochlear and patellar angles; but other interesting points can be described:

- *the gradient of the lateral slope* of the trochlea: this is the angle formed by a line tangential to the lateral slope of the trochlea and the posterior bicondylar line on the cut through the highest part of the trochlea. Its value in our series was 22°, SD 5.5°. This measure, with the trochlear angle, is in fact an indirect measure of the depth of the proximal part of the trochlea (Fig. 13);
- *the patellar tilt* is measured on a cut passing through the middle of the patella; it is the angle formed by the transverse axis of the patella (easier to determine than the lateral articular surface) and the posterior bicondylar line. It was 10° in our series. A more marked tilt (above 20°) indicates a dysplasia of the m. vastus medialis (Fig. 14);
- *patellar subluxation* is measured by the angle of congruence when the latter is measured on the axial view with the knee flexed 30°. Subluxation can be measured in millimeters, by taking as points of reference the median crest of the patella and the depth of the trochlear groove; perpendiculars from these two points are dropped to the posterior intercondylar line, where the distance apart is measured. It is positive if it is lateral in relation to the trochlear groove, and negative when medial. Its value is normally +2.5 mm. These 2 measures, tilt and subluxation, are made on films of the knee in extension, with quadriceps relaxed, and on dynamic cuts;
- *factors consequent upon the physiology of the femoropatellar articulation:* TA-GT of Bernageau and Goutallier [1]: this measurement is obtained by superimposition of the cut passing through the highest part of the trochlea and the cut passing through the tibial tuberosity. Perpendiculars are dropped from the points marking the depth of the trochlear groove (GT) and the middle of the tibial tuberosity (TA) to the posterior bicondylar line. The distance TA-GT can be measured in millimeters, taking account of magnification. This measure expresses the sum of lateral positioning of the tibial tuberosity and lateral rotation of the knee, which, when it exists, is exaggerated. Its value in our series was 12 mm, SD4 (Fig. 14).

The angles of torsion are obtained by superimposing the different films and making a tracing, or, better, reconstructing on a computer.

- femoral anteversion is the angle formed by the axis of the femoral neck and the posterior bicondylar line. In our series this was 11°, SD7.
- rotation of the knee is the angle between the bicondylar axis and the posterior axis of orientation of the tibial epiphysis; in our series it was 3.2° SD3.7.
- lateral tibial torsion is the angle formed by the posterior axis of orientation of the tibial epiphysis and the bimalleolar axis. This lateral tibial torsion has a very indirect influence on femoropatellar function. Its value in our series was 33°, SD8.

Discussion and conclusion

Understanding of the radiological anatomy of the femoropatellar articulation leads to better understanding of femoropatellar pathology and particularly to the conditions of patellar instability. In the pathology can be distinguished certain anatomical factors which are operative; these are major, minor, and more remote.

The major factors: examples are trochlear dysplasia of type I and particularly types II and III, patella alta with an index above 1.2 and a TA-GT measurement above 16 mm.

In the dynamic CT study a lateral tilt of the patella in extension above 20°, with m. quadriceps relaxed, indicates disequilibrium between the medial and lateral vasti, and particularly dysplasia of the oblique m. vastus medialis, as described by Lieb and Perry [11].

Minor factors are a poor lateral slope of the trochlea less than 11°, a trochlear angle above 145°, and exagerated rotation of the knee more than 8°.

More remote factors include marked femoral anteversion more than 19°. In the surgical treatment of patellar instability adjustments are made according to the anatomical anomalies: lowering the patella, moving medially the tibial tuberosity that is too lateral, plastic procedures on the vastus medialis using part of the lateral patellar retinaculum, and trochleoplasty to improve the articulation.

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