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Arthrosis of the knee in chronic anterior laxity*©

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ABSTRACT

Arthrosis following rupture of the anterior cruciate ligament has been analysed in two series. The first series was derived from a review of 150 cases of reconstruction of the anterior cruciate ligament with a follow-up of 3 years or more. Arthrosis was seen to have developed in 13.3%. The second series was concerned with 64 cases of unilateral arthrosis treated by upper tibial valgus osteotomy in whom there had been a previous rupture of the anterior cruciate ligament. The 'tolerance interval' – that is the time between the original ligamentous injury and the time of osteotomy – for the development of arthrosis was very variable, ranging in the natural-history cases from 10 to 50 years, with a mean of 35 years. It is important to recognise the radiological signs of the onset of arthrosis. These are osteophytosis of the intercondylar notch, osteophyte formation at the posterior part of the medial tibial plateau, and, in particular, narrowing of the medial joint line with posterior subluxation of the medial femoral condyle, well seen in lateral radiographs whilst standing on one lower limb. Early arthroses, appearing after 10 years, may occur as a 'natural arthrosis', but it develops much more frequently after surgical treatment that had failed to correct anterior laxity and particularly when it had been performed on knees that were already pre-arthritic. The main factor in arthrosis is anterior laxity measured radiologically by an 'active Lachman' radiograph. Removal of the medial meniscus which in itself is liable to produce arthrosis, is even more harmful in anterior cruciate laxity since it doubles the degree of anterior subluxation of the tibia seen on unilateral weight-bearing. The development of varus deformity, which characterises progressive arthrosis, has its origin in wear of the posterior part of the medial tibial plateau caused by anterior cruciate laxity. Other factors play an important part such as associated lateral laxity, constitutional genu varum and weakness of the hamstring muscles, which oppose the subluxating action of the quadriceps.

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1. Introduction

Although the risk of knee osteoarthritis after injury to the anterior cruciate ligament (ACL) has been well documented by both experimental and clinical studies [1,3,4,6,8,9], the frequency and course of this complication remain unclear. Its importance, however, has been demonstrated by J.-C. Imbert [5], who studied the natural history of ACL injury, and by J.-H. Aubriot and P. Rivat [2], who investigated post-operative osteoarthritis. Statistics for revision surgery after ligament injury often fail to provide information on osteoarthritis, and details are often insufficient on the type of radiograph used to establish the diagnosis. The objectives of our work are to describe the early stages of osteoarthritis, to identify causative biomechanical factors, and to shed light on the crucial issue of lesion potential for progression.

2. Study material

Our study relies on two very different sources of statistical data. 1 – The first source is a study of osteoarthritis detected during re-evaluation in 150 cases of chronic anterior knee laxity treated with ACL reconstruction using a free transplant harvested from the middle third of the patellar tendon, combined routinely with an anterolateral fascia lata graft as described by Lemaire [7]. All these patients were re-evaluated, after 3 to 6 years, the mean follow-up being 4 years.

In this study, osteoarthritis was defined chiefly according to the radiographic findings. At re-evaluation, the work-up included comparative radiographs of both knees with an antero-posterior single-leg-stance view, a lateral single-leg-stance view with the knee flexed at 30°, and a 30° axial view of the patella. Osteoarthritis was defined as joint space narrowing by 50% or more on at least one radiograph combined with osteophytes. We defined pre-osteoarthritis as joint space narrowing by less than 50% and


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developed to osteotomy, high osteoarthritis, of ability way, medial often injury. normal ing remaining medial were development in injuries. These treated patients. We believe these patients illustrate the development of osteoarthritis as part of the natural history of ACL injury. These 20 cases constitute our natural-history group (Fig. 1). In 24 other patients, meniscal signs prompted resection of the medial meniscus. After this procedure, the episodes of knee locking and pain resolved but the knee remained weak, tending to give way, although a return to a measured level of sports participation was possible in some patients. We believe these patients illustrate the natural history of ACL injury with medial meniscectomy. The remaining 20 patients had been diagnosed with ACL injury and treated with a number of procedures on the ligaments before our evaluation at the stage of osteoarthritis.

In the 44 patients providing information on the natural history of ACL injuries with or without meniscectomy, we found convincing evidence of ACL injury. A palpable clunk was identified as the cause of the long-standing instability in 42 of these patients, and the remaining two knees had marked anterior translation in both flexion and extension: a: antero-posterior single-leg-stance view; b: lateral view in the supine position; c: lateral single-leg-stance view; note the posterior subluxation of the medial condyle; d: active Lachman radiograph: 13 mm.

Our classification of our patients may seem open to criticism, as osteoarthritis can cause injury to the ACL. To avoid this pitfall, we did not include patients with highly advanced osteoarthritis and irreducible subluxation.

In the included patients, we believe that the very long history of clinical symptoms constitutes definitive evidence of a traumatic ACL injury in the distant past. In all likelihood, the number of cases of osteoarthritis induced by chronic anterior laxity is far greater. Indeed, we did not include patients with global osteoarthritis, as involvement of the lateral tibio-femoral compartment eliminates the palpable clunk. Neither did we consider patients with bilateral osteoarthritis, as we wanted to conduct a detailed evaluation of the contralateral healthy knee. Nevertheless, ACL injury is bilateral in a noticeable proportion of cases (9%) (Fig. 2).

This second statistical study in 64 patients seen at the stage of advanced osteoarthritis and having a history of ACL injury in the remote past is of particular interest, as it provides information on the tolerance interval, which we define as the time from the sprain to the tibial osteotomy.

3. Radiological findings in osteoarthritis secondary to anterior cruciate ligament injury

Two patterns of osteoarthritis progression were observed:
the most common was medial tibio-femoral osteoarthritis with a shift in knee alignment to varus;
more rarely, global osteoarthritis involving both tibio-femoral compartments occurred, with no progressive deformity in the coronal plane;

We believe that osteoarthritis of the lateral tibio-femoral compartment, found by Aubriot in 10% of cases, is even less common. No cases occurred in the group of surgically treated patients (here, we are excluding the development of osteoarthritic remodelling, which is common after lateral meniscectomy). A single patient with advanced osteoarthritis of the lateral tibio-femoral compartment had a typical history for ACL injury in the distant past, with anterior subluxation of the tibial plateaus. However, given the absence of a palpable clunk, this patient was not included in our retrospective study (Fig. 3).

Medial tibio-femoral osteoarthritis: the antero-posterior radiograph shows that the single-leg stance worsens the joint space narrowing, with mild lateral subluxation of the tibia, which tends to increase over time. As soon as subluxation occurs, osteophytes develop in the lateral tibio-femoral compartment.

The lateral radiograph clearly shows anterior subluxation of the tibia, with increasing downwards displacement of the medial condyle posteriorly and internal rotation of the femur relative to the tibia. Varus deformity of the knee opens the lateral joint space, a finding that we designate ‘lateral decoaptation’. This abnormality is mild or absent. It is often considerably less marked than in usual medial tibio-femoral osteoarthritis, except in the event of marked bony varus deformity.

Global tibio-femoral osteoarthritis is characterised by marked production of osteophytes both on the two tibial plateaus and in the notch. The joint space narrowing also involves both compartments. The patello-femoral joint rapidly becomes involved, with osteophyte production and overall joint space narrowing. Patients with this anatomic pattern were considered only for the study of post-operative osteoarthritis. Indeed, this pattern of osteoarthritis alters the results of dynamic knee testing, thus severely hindering the ability to make a retrospective diagnosis of chronic anterior laxity. Nevertheless, we believe this pattern is far from uncommon among non-operated patients. Furthermore, we eliminated at least 10 cases seen at the stage of advanced osteoarthritis in athletes with a history of major surgery (e.g., bilateral meniscectomy or joint debridement). Although a definite diagnosis of ACL injury cannot be made retrospectively, such an injury appears highly likely.

– The study of our cases suggests that osteoarthritis complicating anterior laxity exhibits a number of distinctive features. Nevertheless, none of these features can be considered pathognomonic, at least at the stage of advanced osteoarthritis. In contrast,
in early osteoarthritis with no marked or irreducible deformities, the location of the osteophytes and joint space narrowing consistently reflects the biomechanical disturbances responsible for the osteoarthritis.

We believe that the following four signs deserve special attention:

- **tibio-femoral remodelling:** these changes have long been known to occur after meniscectomy. Osteophytes develop on the condyles and tibial plateaus, in combination with some degree of condylar flattening. We believe that a characteristic feature in ligamentous laxity is the involvement of both compartments, which very often – although not always – reflects a bilateral meniscal lesion. Furthermore, bilateral meniscal lesions are rare in the absence of anterior laxity.

- **osteophytic remodelling of the intercondylar notch** is, in our opinion, even more important and more characteristic. It produces the very classical hook-like appearance of the tibial spines. A view of the notch shows, in addition to these tibial osteophytes, femoral osteophytes developed on the axial aspects of both condyles and tending to fill the intercondylar notch. This pattern is a well-known intra-operative finding. When found during ACL reconstruction surgery, the notch must first be cleared by removing the osteophytes. Although this sign no longer has any value in advanced osteoarthritis, we believe it is nearly pathognomonic in early osteoarthritis complicating chronic anterior laxity and characterised by little or no joint space narrowing.

- **posterior tibial osteophytosis** is clearly visible on the lateral view. We feel this is an excellent sign at the early stage. The osteophyte is horizontal and prolongs the medial tibial plateau posteriorly. The value of this sign is greatest when examining the lateral single-leg stance view with the knee at 30° of flexion. On this view, the initial narrowing is visible at the posterior part of the medial tibial plateau, as a small posterior concavity that is prolonged posteriorly by the posterior osteophyte. In contrast, in idiopathic osteoarthritis, the osteophyte is directed vertically.

- **the last characteristic sign** is a good illustration of the laxity responsible for the osteoarthritis. On the lateral single-leg stance view, anterior subluxation of the tibial plateaus is visible, with the medial condyle dropping downwards in the posterior concavity of the medial tibial plateau and seeming to rest on the posterior osteophyte.

### Table 1
First study population. Re-evaluation after ACL reconstruction (150 cases).

<table>
<thead>
<tr>
<th>NB</th>
<th>Normal radiographs</th>
<th>Remodelling</th>
<th>Pre-OA</th>
<th>OA</th>
<th>Meniscal lesion</th>
<th>Both menisci</th>
<th>Radiological Lachman</th>
<th>Prior surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MM</td>
<td>LM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal radiographs</td>
<td>90</td>
<td>37</td>
<td>10</td>
<td></td>
<td>3</td>
<td>6.31</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Remodelling</td>
<td>40</td>
<td>15</td>
<td>4</td>
<td></td>
<td>13</td>
<td>6.77</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Pre-OA</td>
<td>7</td>
<td>5</td>
<td>0</td>
<td></td>
<td>2</td>
<td>8.60</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>OA</td>
<td>13</td>
<td>8</td>
<td>1</td>
<td></td>
<td>4</td>
<td>10.33</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

4. Analysis of the first study population

Here, we will study the 20 cases of osteoarthritis and pre-osteoarthritis identified at re-evaluation of 150 patients with surgically treated anterior laxity (Table 1).

Among them, six had global osteoarthritis and 14 medial tibio-femoral osteoarthritis. Six patients had noticeable functional impairments (including three in whom we performed secondary valgus high tibial osteotomy and three others to whom we suggested this procedure). The remaining 14 patients had virtually normal function; most of them engaged in recreational sports (ski, tennis, running, biking) and three were competition soccer players (Fig. 4). A number of factors may explain these cases of early osteoarthritis:

- **pre-operative abnormalities:** the pre-operative radiographs were completely normal in only seven patients. In the 13 other patients, they showed osteoarthritic remodelling of either the notch or the tibial plateaus, combined in nearly half the cases with slight narrowing of the medial tibio-femoral joint space. Thus, knees characterised by obvious pre-osteoarthritic abnormalities respond very poorly to reconstructive surgery, particularly in patients older than 30 years.

Another factor of markedly adverse prognostic significance is a history of surgery before the reconstructive procedure. A variety of surgical procedures had been performed, but they nearly always included medial meniscectomy. Among the 150 patients who were re-evaluated, 19.5% of those who had normal radiographs had a history of prior surgery, compared to 44.7% of those whose radiographs showed osteoarthritic remodelling. Among patients with osteoarthritis, 70% had a history of prior surgery.

- **the influence of meniscal lesions is also considerable.** Among patients with osteoarthritis, only one had a normal medial meniscus, 13 had meniscectomy performed before the reconstruction, and five had meniscectomy performed during the reconstruction. In one patient, the meniscus was repaired at the same time that a damaged lateral meniscus was removed; the subsequent radiological course was identical to that seen after meniscectomy. Removal of the lateral meniscus seems less deleterious. In contrast, removal of both menisci carries a very high risk of osteoarthritis:

- **cartilage lesions** are also very often found during the procedure, in keeping with the radiological finding of joint space narrowing. Chondritis of the medial tibial plateau was noted in nine cases (45% versus 13% in the overall study population). A single patient had cartilage damage on the medial condyle.

- **pre-operative laxity:** in most cases, the degree of laxity was considered very severe. Unfortunately, we do not have information on the radiological Lachman test. The clinical Lachman test and the drawer tests with the knee flexed had received the highest possible score (++). In addition, a voluntarily evoked positive drawer test was present in two patients, and in nine patients posterior-medial plasty (Helfet-Slocum technique) was deemed useful, a fact that indicates marked distension of the postero-medial corner. Osteoarthritis developed in over one-third of the cases of anterior laxity, which was particularly marked in the overall study population. It should be pointed out that this factor was very often combined with a prior history of surgery.

External laxity also plays a role. The only case of osteoarthritis in a knee with a normal medial meniscus is of particular interest. Initially, the laxity was moderate with a negative drawer test in flexion but with marked lateral laxity and a 3-cm genu varum deformity. Surgery consisted in removal of the damaged lateral meniscus and re-tensioning of the lateral collateral ligament. At re-evaluation, the Lachman test was only 6 mm, the osteoarthritis was confined to the coronal plane with no posterior concavity or osteophyte, and the lateral decapitation was very markedly increased;
5. Analysis of the second study population

In this study of 64 cases of unilateral osteoarthritis managed with tibial valgus osteotomy, the most important point in our opinion is the time from the injury to the osteotomy, or tolerance interval (Table 2). In all cases, the injury occurred at the usual age (mean, 23.7 years). The tolerance interval in the natural-history group (no ligament repair or meniscectomy) was 35 years (range, 10–50 years). In the natural-history + MM group (meniscectomy but no ligament repair), the tolerance interval was only 25 years (range, 8–52 years). Finally, in the group with ligament repair, osteoarthritis developed considerably earlier, the mean tolerance interval being only 11 years (range, 2–32 years) (Table 2).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Second study population. Tolerance interval.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural history</td>
</tr>
<tr>
<td>Mean age at sprain</td>
<td>22.2</td>
</tr>
<tr>
<td>Mean age at osteotomy</td>
<td>57.3</td>
</tr>
<tr>
<td>Tolerance interval</td>
<td>35 years</td>
</tr>
</tbody>
</table>

The osteoarthritis in the natural-history group exhibited several characteristics of interest. The most salient finding is the proportion of women. Overall, in studies of ACL injury, females rarely contribute more than one-third of cases (Table 3). Although the difference between the proportions of men and women is decreasing as women increasingly participate in sports, the same was not true 20 or 30 years ago. Furthermore, none of these patients engaged in sports, had particularly strenuous occupations, or exhibited a degree of overweight likely to influence the development of osteoarthritis.

In addition, we found no evidence of pre-existing malalignment, as assessed by examination of the normal knee. Coronal alignment was consistently about 5° of valgus, which is considered normal.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Second study population: tibial valgus osteotomy to treat osteoarthritis complicating chronic anterior laxity (64 cases). Sex distribution.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>No ligament repair or meniscectomy</td>
<td>20</td>
</tr>
<tr>
<td>Medial meniscectomy but no ligament repair</td>
<td>24</td>
</tr>
<tr>
<td>Osteoarthritis after ligament repair</td>
<td>20</td>
</tr>
</tbody>
</table>
The abnormal knee was unstable but generated only a moderate degree of impairment, with good compensation until the development and gradual exacerbation of pain due to osteoarthritis. The development of osteoarthritis did not influence the instability in internal rotation, which even increased in some cases.

In the natural-history+MM group, the clinical history of the osteoarthritis was somewhat different. The predominance of women was less marked than in the natural-history group, and the meniscectomy was nearly always performed within a few years after the injury. Although half the patients were able to resume recreational sporting activities (tennis, skiing), they could not engage in high-level sports and were never fully asymptomatic but were well aware of their limitations. Again, we found no marked alignment abnormalities except for a possibly excessive degree of varus in four cases.

For these cases of osteoarthritis in the natural-history patients with or without meniscectomy, age at occurrence of the injury did not seem to significantly influence the tolerance interval. Thus, the frequency of rapidly progressive forms of osteoarthritis was similar in the very young patients and in the patients older than 35 years of age. The degree of laxity is, of course, difficult to assess. In every case, the Lachman test and anterior drawer test in flexion received the highest possible score in our scale (++). The radiological Lachman test was performed in only about 10 patients; it consistently showed a far greater degree of anterior subluxation than on the lateral single-leg stance view. The posterior osteophyte hindered the radiological measurements. The displacements were always particularly large, ranging from 12 to 18 mm. Lateral laxity was considered abnormal compared to the contralateral knee in only five cases, and lateral decoaptation was often minimal or absent.

The cases of osteoarthritis after ligament repair surgery showed considerably greater variability. Details on the ligament repair procedure were not available for all patients:

- in three patients, osteoarthritis developed after surgery for recent-onset laxity. The time to osteoarthritis was shortest by far in these patients. Osteotomy was performed twice or three times after the sprain. In these three patients, major surgical procedures had been performed (Lindeman procedure, Kenneth-Jones procedures, and lateral tenodesis according to Lemaire reconstruction combined with suturing and with an apparently complex procedure on the medial capsule and ligaments, respectively). In contrast, the medial meniscus was either left untreated or sutured. The post-operative course was similar in these three patients: cast for 45 days, difficult rehabilitation therapy, and marked stiffness requiring mobilisation under general anaesthesia (on several occasions in one case). Clearly, these cases form a distinctive group in which the osteoarthritis can be ascribed neither to the laxity-induced intra-articular lesions, nor to the laxity itself, since dynamic tests were not performed and the translation during the Lachman test was very small. Instead, the immobilisation in a cast followed by stiffness is undoubtedly a causative factor that probably indicates a mild form of sympathetic reflex dystrophy. In this situation, mobilisation under general anaesthesia can be extremely aggressive for the cartilage, resulting in chondrolysis;
- in the patients with osteoarthritis after surgical treatment of chronic laxity, the variability and lack of detail on the procedures precludes a rigorous analysis. We will simply point out the following features:
  - high frequency of repeated procedures that always included, at some point, a medial meniscectomy, which was probably complete; in some cases both menisci were removed;
  - performance of complex medial reconstruction procedures (Nicolas, Don O’Donoghue);
  - in three cases, Lemaire antero-lateral tenodesis combined with medial meniscectomy;
  - finally, persistence in all these patients of marked anterior laxity as assessed by the anterior drawer and Lachman tests.

6. Factors involved in the genesis of osteoarthritis

To study these factors, we will rely chiefly on the data from our first population, in which the available documents illustrate the development and progression of the osteoarthritis. We will separate the abnormalities into four groups:

- intra-articular lesions;
- anterior laxity;
- lateral decoaptation;
- and patient-related factors.

1 – Intra-articular lesions

a – Cartilage lesions. These lesions are produced by abrupt anterior subluxation of the tibia during the clunk that occurs in valgus-extension or internal rotation. They predominantly involve the medial condyle and consist in true crush-fractures of the cartilage caused by abrupt subluxation of the medial condyle at the posterior part of the medial tibial plateau.

In our experience, fractures of the lateral condylar cartilage are less common, although the main site of impingement is in the lateral tibio-femoral compartment. For a bone and cartilage fracture to occur, the mechanical stress must be both strong and abrupt. A clunk in internal rotation, which is a key form of instability, does not produce such strong stresses, provided the lateral condyle is protected by the thick lateral meniscus. Thus, in contrast to the medial compartment, the lateral compartment develops severe cartilage lesions chiefly after lateral meniscectomy.

These cartilage lesions are responsible for pain and chronic knee effusions, particularly when they affect the lateral compartment. In contrast, at least in the absence of meniscectomy, they do not seem to have resulted in early osteoarthritis. On the other hand, atrophic chondritis of the posterior part of the medial tibial plateau was consistently associated with prior medial meniscectomy or with pre-operative evidence of meniscal damage. These lesions were of very poor prognostic significance: nearly half the patients with osteoarthritis after ligament reconstruction had such lesions, which were consistently accompanied with osteoarthritic remodelling when this abnormality was not already present pre-operatively. Whereas the condylar lesions reflected an acute event related to the instability, the tibial lesions in our opinion were related to a completely different factor, i.e., the onset of osteoarthritis after ACL injury.

b – Meniscal lesions: Removal of the medial meniscus, particularly when complete, is a well-recognised risk factor for medial tibio-femoral osteoarthritis. When meniscectomy is performed, the existence of peripheral meniscal detachment, which is highly characteristic of chronic anterior laxity, mandates complete meniscectomy. The data from our first study population clearly illustrate the role for meniscectomy in osteoarthritis (Table 1). Very often, meniscectomy is followed by the swift development of osteoarthritic remodelling of the medial tibio-femoral compartment: nearly all our patients with osteoarthritis had a history of medial meniscectomy. Thus, the role for meniscal meniscectomy in the genesis of osteoarthritis is undeniable, although it does not fully explain the lesions.

Medial meniscectomy in patients with anterior laxity is not comparable to isolated medial meniscectomy. Medial meniscectomy not only modifies load distribution on the tibial plateau, but
also increases the laxity, often to a considerable extent. We will therefore come back to this issue in the discussion of laxities.

2 – Anterior laxity (Fig. 5)

When the ACL is torn, the characteristic type of laxity is anterior tibial subluxation when the knee is extended. This subluxation is a direct translation, without rotation, as shown by passive or dynamic lateral radiographs. As demonstrated by Lecœur, contraction of the quadriceps places the ACL under tension. We designate this effect by the term ‘active Lachman test’, which forms the basis for our study. We performed this test bilaterally in 100 patients with unilateral ACL tears. Some degree of constitutional laxity is common, and mean translation during the Lachman test in normal knees is 3.2 mm (range, 0–6 mm). When the ACL is torn, translation during the Lachman test increases to a mean of 10 mm and there is consistently a difference of at least 5 mm with the contralateral normal knee. Mean Lachman test translation is 6 mm in knees with isolated ACL injury and 12 mm in those with ACL injury and meniscectomy. This finding indicates that involvement of the postero-medial corner considerably worsens the anterior laxity, not only in flexion, but also in extension (Fig. 6).

On the lateral single-leg-stance radiograph with the knee flexed to 20°, the anterior subluxation of the tibia is also visible, although far more variably and less prominently. This radiographic view is chiefly illustrative when meniscal meniscectomy has been performed or the postero-medial corner is substantially distended. This tibial subluxation during single-leg weight bearing has obvious consequences. Walking and, above all, climbing down stairs, running, and jumping result in mechanical stresses that are more than sufficient to cause, at each contact with the ground, an impact of the condyle on the posterior edge of the tibial plateau. These condylar impacts result in development of the posterior osteophyte and in gradual wear of the medial plateau into a concave shape, while also causing long-silent fibrillation of the posterior horn of the medial meniscus. We believe this is the main cause of osteoarthritis related to chronic anterior laxity.

Two radiographic findings of special interest are osteoarthritis of the notch, which is a highly specific feature of early chronic anterior laxity; and cup-like wear of the posterior part of the medial tibial plateau. These radiographic changes are consistent with repeated direct anterior subluxation of the tibia relative to the femur. The inter-condylar notch glides forwards and backwards on either side of the tibial spines. The active Lachman radiographs and radiographs in single-leg-stance with the knee flexed at 20° show that, when the ACL is torn, the anterior tibial subluxation is triggered by the combination of quadriceps contraction and single-leg stance. The displacement measures a few millimetres when the ACL is torn but rapidly exceeds 1 cm in the event of antero-medial laxity.

The role played by anterior laxity during knee extension in the development of osteoarthritis is clearly illustrated by our study.

In the natural-history patients with osteoarthritis, the radiological Lachman displacement, when measured, was consistently between 15 and 18 mm. In the ACL reconstruction group re-evaluated after at least 3 years, the patients with very early osteoarthritis often had a Lachman displacement of 15 to 17 mm. The mean Lachman displacement of 10.33 mm in the patients with osteoarthritis only imperfectly illustrates this point. Indeed, these patients with osteoarthritis fell into two clearly different groups: 15 had high Lachman values of 10 to 17.5 mm and the remaining five had fairly low Lachman values of 3 to 8 mm. This last subgroup demonstrates, as discussed below, that the factors responsible for osteoarthritis can vary across patients, although we believe that anterior laxity plays a predominant role. When the anterior laxity is marked and the osteoarthritis advanced, the active Lachman radiograph and the lateral single-leg-stance radiograph are interesting to compare: the type of anterior subluxation differs. On the active Lachman radiograph, the subluxation is direct, with both tibial plateaus displaced forwards and nearly always symmetrically. On the lateral single-leg-stance view, in contrast, particularly when the anterior laxity is marked, the anterior subluxation involves internal rotation of the femur, indicating that the varus loads caused by weight bearing markedly worsen the posterior subluxation of the medial condyle relative to the lateral condyle, which shows little or no subluxation.

In all likelihood, in a certain number of cases, particularly in patients with hyperlaxity, gradual distension of the postero-medial corner may occur, even in the absence of a new trauma, with gradual disappearance of the medial meniscus. This mechanism may explain the development of osteoarthritis after several decades in non-athletes.

In general, the vicious circle leading to osteoarthritis starts as soon as damage to the meniscus occurs. We know that absence of the medial meniscus considerably increases the anterior laxity in extension, thereby allowing posterior subluxation of the medial condyle during weight bearing. The result is posterior condritis of the medial tibial plateau, which is the first true osteoarthritic lesion. This mechanism also explains the risk of osteoarthritis associated with sports practiced intensively by a patient with chronic laxity. The risk of progressive osteoarthritic is low as long as the translation in extension is small and the medial meniscus normal. Otherwise, abrupt loading during single-leg weight bearing very rapidly causes wear of the posterior cartilage.

Whether or not the clunk persists is unrelated to the risk of osteoarthritis. We believe the risk of osteoarthritis is greatest when the surgical procedure eliminates the impingement, which provides good stability, allowing the resumption of sports but leaving a marked degree of translation in extension.

3 – Lateral decoaptation and varus malalignment

Lateral laxity that allows varus malalignment during single-leg weight bearing magnifies the loads through the medial tibio-femoral compartment and, therefore, increases the risk of osteoarthritis. Constitutional bony varus malalignment exacerbates the effects of lateral laxity. We believe this combination of lateral laxity and varus deformity is the second major factor in the genesis of osteoarthritis.
There are three questions of interest:

- Does a tear in the ACL cause ‘lateral decoaptation’, as argued by Bousquet?
- Does gradual stretching of the postero-lateral structures occur over the years, a mechanism suggested as the main factor in osteoarthritis complicating chronic laxity?
- Given that surgical procedures on the fascia lata decrease the strength of the lateral tension stays, can they worsen the lateral laxity?

1 – We will use the term ‘lateral decoaptation’ to designate the gaping of the lateral joint space that occurs between a radiograph in the supine position and a radiograph in single-leg stance. This concept incorporates a broad range of components: the lateral laxity strictly speaking, the pattern of coronal alignment, the strength of the lateral tension stays, and the narrowing of the medial joint space. We believe that lateral decoaptation is of interest, because it is easily seen on radiographs. It constitutes a clear illustration of the mechanical conditions imposed on the knee during single-leg weight bearing. However, lateral laxity may have little or no consequences under static conditions, whereas the gaping is undoubtedly more marked when strong mechanical stresses are applied (e.g., during running or jumping). When investigating osteoarthritis, we believe, however, that this simple concept is the most appropriate, as it perfectly reflects the coronal alignment disorder. In our study of patients with unilateral chronic anterior laxity, the pre-operative antero-posterior single-leg-stance radiographs of both knees showed the following:

- the radiographs were symmetrical in 60% of cases including 40% with no lateral decoaptation and 20% with lateral decoaptation on both sides; the overall correlation noted between decoaptation and varus deformity was not absolute, as the presence of hyperlaxity and constitutional stiffness had a major influence, explaining in our opinion why decoaptation was absent in some knees with marked genu varum deformity and present in other knees with genu varum;
- the radiographs showed asymmetrical decoaptation in 40% of cases. However, in 30% of cases, the medial joint space was narrowed as a result of medial compartment lesions (meniscectomy, meniscal damage, chondritis). The shift to varus malalignment in this situation seemed far more closely dependent on the loss of medial compartment height than to the lateral laxity. In 10% of cases, in contrast, the medial compartment was completely normal and the role for the ACL tear was therefore undeniable. In most, but not all, these cases, there was clinical evidence of disruption of the postero-lateral corner with recurvatum and excessive external rotation.

2 – Our study of the natural history of laxity with or without meniscectomy showed no evidence of gradual stretching of the postero-lateral ligaments. Of 64 patients managed with osteotomy, only five had abnormal and asymmetric lateral laxity, corresponding to the population with abnormal decoaptation mentioned above. The clinical tolerance interval in these patients was similar to that in the other patients, suggesting that even in this situation the external laxity antedated the osteoarthritis, i.e., was not caused by the natural disease progression.

3 – The third question is important, since lateral reconstruction using the fascia lata is widely used today. In particular, we perform a Lemaire-type tenodesis in nearly every case.

- In 23 of 150 cases, the lateral decoaptation worsened very slightly but undeniably. This subgroup includes the 10 patients with osteoarthritis discussed above, in whom the shift to varus malalignment is clearly entirely ascribable to the medial wear.
- In 9 other cases, an additional feature was narrowing of the medial joint space, which was consistently related to medial meniscectomy, combined in some cases with chondritis. Thus, the features in this group closely resemble our definition of pre-osteoarthritis. We did not classify these patients in the pre-osteoarthritis group, however, because the joint space narrowing was very small and was not accompanied with bony contact, osteophytes, or sclerosis. Although there is little doubt about the long-term course in these cases, it is worth noting that the laxity was well corrected, with an active Lachman consistently below 10 mm. This fact may have prevented the development of early osteoarthritis. Whether or not this is the case, we believe the lateral decoaptation cannot be ascribed to harvesting of the fascia lata.

- In the remaining 4 cases, the medial joint space remained strictly normal and lateral distension was clearly present. Correction of the anterior laxity was excellent (Lachman, 8.7 to 5.7 mm), but very marked varus deformity was a consistent feature, with a mean of 5.7 cm and a range of 4 to 7 cm. Such distension is not consistently found, however, since of the 20 knees with genu varum deformity and follow-ups longer than 4 years in our study group, only 4 exhibited lateral distension.

In conclusion, the harvesting of a 1 cm-wide ribbon of fascia lata followed by accurate reconstruction of the fascia lata does not appear to be a major factor in the development of lateral distension, in the absence of marked constitutional varus deformity.

4 – Patient-related factors and sports (Fig. 7)

Participation in sports undoubtedly exerts a powerful effect in accelerating the development of osteoarthritis. After an ACL tear, most cases of early detachment or rupture of the medial meniscus occur during sporting activities. The efforts made during sports increase the loads that promote anterior subluxation and lateral decoaptation, thereby resulting in wear of the posterior part of the medial tibial plateau. Resolution of the instability allows the patient to resume participation in sports and may therefore be viewed as having a deleterious effect, in the absence of concomitant correction of the anterior laxity in extension. However, the situation is
more complex: as mentioned above, in our natural-history study, osteoarthritis developed even in non-athletes, albeit after a long time interval. Furthermore, our cases suggest differences in the pattern of osteoarthritis between athletes and non-athletes. Distension of the postero-medial corner and anterior tibial subluxation seem considerably less marked, whereas lateral lesions are usually present. These two factors combined contribute to the development of global osteoarthritis, which, despite the severe radiological changes, is often very well tolerated, allowing strenuous sporting activities and inducing only limited functional impairments. Thus, participation in sports results in early osteoarthritis but also promotes the development of a balance that decreases the functional impact and progression of the osteoarthritic lesions. We suggest the following hypothesis to explain these facts.

- The only force that can counteract the anterior tibial subluxation comes from the hamstring muscles. If these muscles are well developed, they may avoid the rapid development of postero-medial corner distension. The occurrence of osteoarthritis in our natural-history population may constitute an *a contrario* argument in favour of this hypothesis. As mentioned above, osteoarthritis chiefly affected women who had no history of intense participation in sports or other physical activities: under these conditions, the knee works chiefly in a position close to full extension, a sector in which the quadriceps, even when weak, predominates over the hamstring muscles. This mechanism may explain the gradual development in these patients of osteoarthritis with distension of the postero-medial structures and protection of the lateral tibio-femoral compartment. In the presence of hyperlaxity (which is far more common in females than in males), the tendency towards genu recurvatum deformity and the deficient muscle tone may diminish the level of protection against osteoarthritis after an ACL tear, compared to patients with stiff joints, a tendency toward genu flessum, and a high level of muscle tone.

7. Discussion–Conclusion

Our data do not allow us to answer the crucial question of the frequency of subsequent osteoarthritis among patients with ACL tears. Our results on the tolerance interval of osteoarthritis during the natural history of ACL tears put this question into perspective: clearly, the approach to osteoarthritis cannot be the same when the disease develops after 10 years, which is a very short period given the mean age at ACL tear occurrence, and when it only becomes problematic after 50 years. The risk of early progressive osteoarthritis should be taken into account not only when surgery is performed, but also when a conservative strategy is used.

We believe that the development and, above all, potential for progression of osteoarthritis after an ACL tear is chiefly dependent on the *anterior laxity in extension*. Naturally occurring disappearance or surgical removal of the medial meniscus triggers the vicious circle that leads to osteoarthritis, allowing posterior subluxation of the medial condyle and lateral decoaptation, which induce knee malalignment during single-leg weight bearing, thereby markedly increasing the loads on the medial structures. To ensure a favourable long-term outcome, the medial meniscus must be preserved and surgical correction of both the instability and the translation in extension must be obtained.

Damage to the ligaments of the postero-lateral corner concomitantly with the ACL tear may also promote the development of osteoarthritis, particularly in knees with marked constitutional genu varum deformity.

Muscle balance plays a non-negligible role. In patients with hyperlaxity and a tendency towards genu recurvatum deformity, the weak hamstring muscles cannot prevent the gradual distension of the postero-medial corner. Rehabilitation exercises focussing on the hamstring muscles as opposed to the quadriceps are therefore crucial to the prevention of osteoarthritis.

Surgery can be responsible for the development of osteoarthritis at a considerably earlier date than during the natural history of ACL tears, if the procedure does not comply with a number of rules.

- Joint stiffness that requires procedures such as manipulation under general anaesthesia or even joint release increases the risk of cartilage damage. Stiffness can be prevented by avoiding complete and prolonged immobilisation in a cast and by applying a rational rehabilitation programme.

- Ligament reconstruction procedures, regardless of their type, are dangerous when performed on a knee that already exhibits signs of intra-articular damage, meniscectomy, or meniscal lesions with chondritis of the medial tibial plateau. The presence of even a tiny degree of joint space narrowing, osteoarthritic remodelling, osteoarthritis of the notch and, above all, a posterior osteophyte arising from the medial tibial plateau warrants a careful assessment of the risk of ligament surgery, which may accelerate the development of osteoarthritis, particularly in patients older than 30 years of age. Decreasing the loads by performing a valgus tibial osteotomy concomitantly with the reconstruction appears essential in the presence of asymmetrical lateral decoaptation, particularly when there is a marked degree of constitutional genu varum deformity.

- Antero-lateral reconstruction procedures such as that described by Lemaire, although effective in restoring stability, may increase the risk of osteoarthritis when the postero-medial corner is distended or the medial meniscus is absent. Indeed, these procedures induce external rotation, thereby exacerbating the posterior subluxation of the medial condyle relative to the medial tibial plateau.

The decision to perform surgery to treat anterior laxity should always rest on an assessment of the functional impairment, which is dependent on the degree of knee instability. Nevertheless, the decision should be taken promptly, particularly in younger patients, since the best means of preventing the development of osteoarthritis seems to be an appropriate surgical procedure performed as early as possible after the ACL tear, before the development of meniscal and cartilage lesions and of distension of the postero-medial corner, which considerably increases the anterior laxity, thereby making ligament reconstruction insufficiently effective or even hazardous.

Disclosure of interest

Authors’ disclosure of conflict of interest was not requested when the article was originally published.
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