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Clinical and Imaging Study of Knee Biomechanics

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Abstract

Knee anatomy and physiology suffer important stress in the frontal, sagittal (anterior-posterior) plan, rotation horizontal plan neutralized by the morphology of the joint surfaces, menisci and anterior-posterior stabilizing formations and in frontal plan due to perfect congruency between the joint surfaces and the tensioning of all ligaments by the internal and external stabilizing system, a ligament rupture does not create from the beginning a joint instability, its function being compensated by the other synergic structures for a longer or shorter time, according to the decompensation appearance.
For a better understanding, from the point of view of the biomechanics and ambulatory functional re-education, after knee surgery, the paper tends to explain the mobility degrees in flexion and extension determined by crossed ligaments, the stabilizing role of the ligaments within the knee cinematic chain complex, the crossed lever mechanism, the Menschik mathematic model of isometrics of the front crossed ligament for the knee articulation and the ligament lesions referring to knee instability, surgery stabilization being more complex and the recovery period shorter.

Key words: *knee, ligament, surgery, tibia,* Menschik model

Introduction

The ligaments main function is to limit the movements in joints, implicit of joint stabilization and the sub sprains and sprains prevention. Any ligament injury changes the articulation limits of movements.

The ligaments capacity to limit the movements is of great importance because between the limits determined like this, the neuromuscular system proprioceptors can control the position of knee and its sustain function, even then in a first phase the musculature can compensate the increase in articulations sprains, further through the muscular atrophy decompensation appears. Responsible for atrophy are the proprioceptors which are situated in the two posterior corners, the semimembrane corner(outside) and the popliteus corner(inside). The two corners are made from four elements. The semimembrane corner is made from the semimembrane muscle fingerings, the inner meniscus with corneal or posterior, the inner collateral ligament and the inner twin insertion.

The extern corner is made from the popliteus tendon, the extern meniscus posterior corner, the lateral collateral and the extern twin insertion (see figure 1). Any pressures, especially in rotation, practiced to this structure produce feed-back reaction and implicit muscular atrophy.

The ligaments practise its stabilizer function through isometrics. This depends on three essential elements: inserts localisation, length and ligament tension.

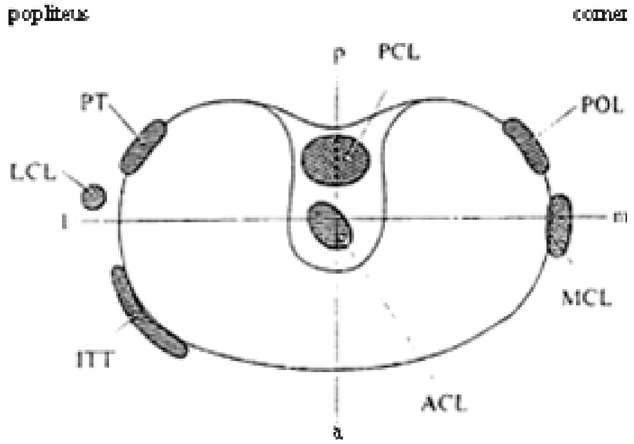

Fig. 1. The popliteus corner and semimembrane corner

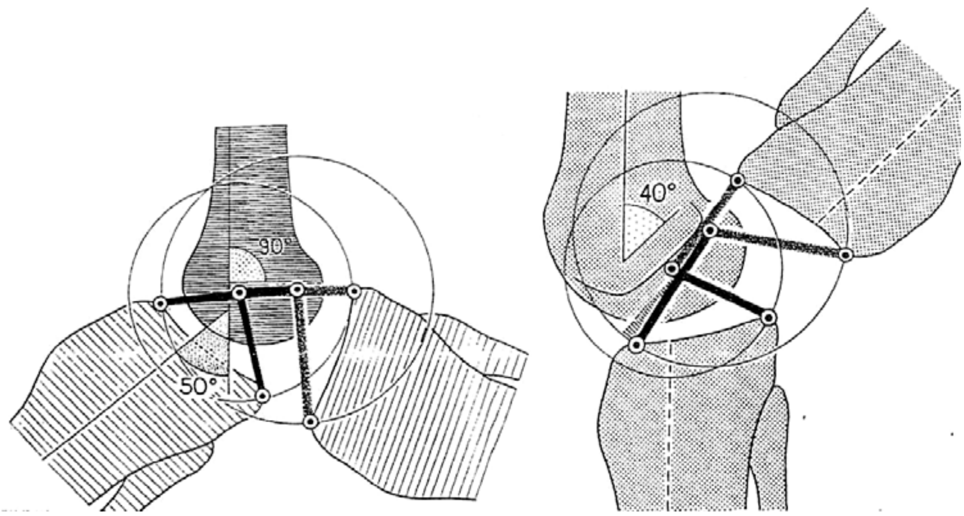

Fig. 2. The mobility grade in flexible extension caused by cruciate ligaments

The knee movements' limits are determined by cruciate ligaments placement. If the proximal origin could spread on a straight line to a 0 degree angle towards the long tibia axle, the knee could have a 50 ÷ 70 degree mobility (see figure 1) to allow a normal 5 ÷ 145 degree mobility, the cruciate ligament tibia origin must be spread on a line which forms a 40 degree angle with tibia long axle.

So happens if the intercondyle_notch roof forms a 40 degree angle with the long axle so to limit the extension and to prevent hyperextension. If the knee is forced in hyperextension, ACL is placed in a critical position with the possibility of bursting (see figure 3). If we look for the moment ligament movement one-dimensional in a plan, with a constant length makes small circular arc, with fix tibia, tibia insertion shows a circular line (see figure 4).

The tibial point of insertion is the centre of circle and in reverse order if the condyle point of insertion moves also, then it is the centre of circle. Of course, this model is valid if we see ACL like a perfect line, but from the sum of fibre which forms the ligament not all could respect this rule. The laws for these ligaments are given by the four cruciate levers mechanism which determine the obligatory movement on the osseous surface with the point of contact posterior change and exclusively conduct this movement(see figure 5). The sequence is efficiently even if ACL is broken and flexion and extension between femur and tibia appear in the same plan.

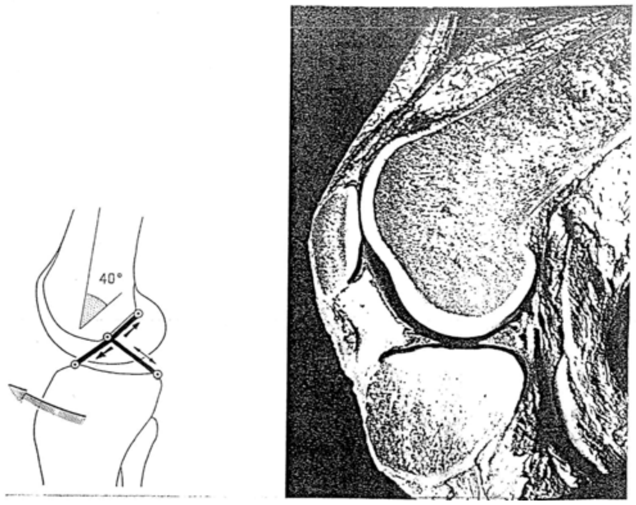

Fig. 3. The ACL critical position in extension

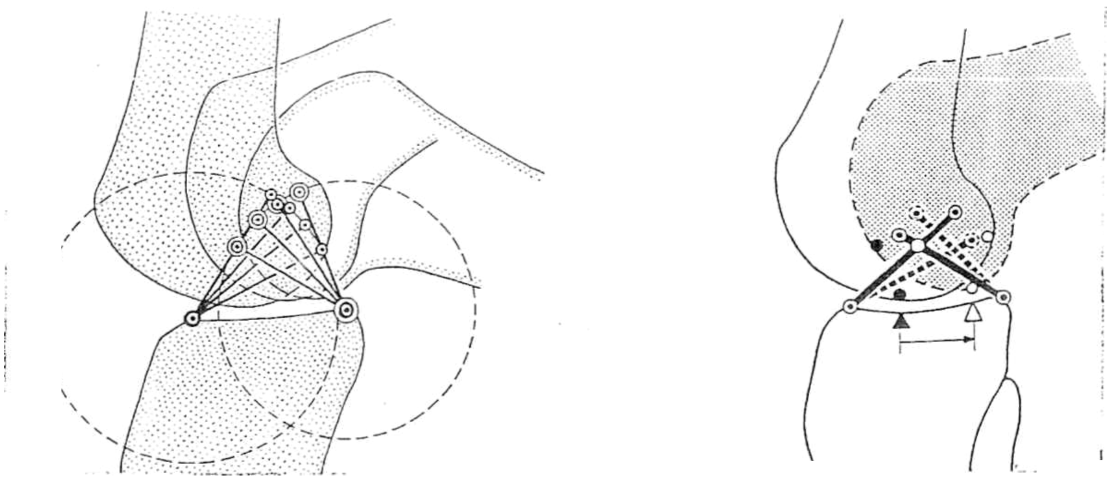

Fig. 4 and 5.The one-dimensional look in a single plan of the ACL four cruciate levers mechanism

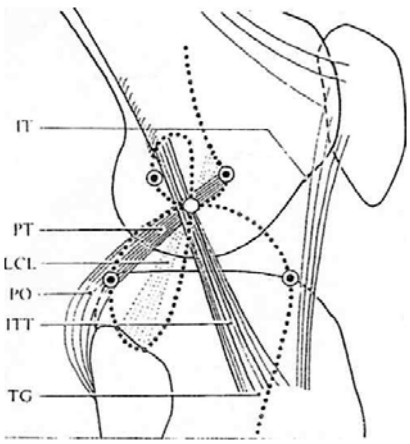

Fig. 6. Keeping the ligament tension

The ligaments length is a condition for the amplitude articulation movements, any extension or damage cause laxity. The ligament tension represents an essential basic element of the ligament isometric. In this way the amplitude of movement is controlled for the developed tension to resist to mechanical charge.

The Menchik Mathematical Model

In 1974, at Technical College from Vienna, Menschik (inspired by German mathematician paper from München, Burmaister, presented since 1888) presented a mathematical model for ACL kinematics. According to this model, the ligament edges always intersect "the pole" or the immediate centre which is located on the transverse axle of flexion. Seeing these lines in a transparent femur we found out that radiate outside the centre like the spoke wheel. These spoke are distributed the same for LCM and ACL. In injuries the two ligaments are grouped the same as in fracture (see figure 6, 7, 8 and 9).

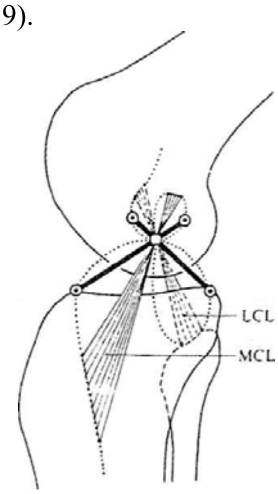

Fig. 7. The Menschik model

At the knee level could be made 6 types of movements, independent to one another: 3 rotation movements and 3 translation movements, each representing a restricted grade of movement because of the ligaments. Looking three-dimensional in this movement each axel permits to show two movements: translation and rotation. The rotation movements are: abduction-flexion, flexion, extension, and inner rotation – extern rotation. The translation movements are: anterior-posterior tibial translation, medium-lateral tibial translation, compression-distraction movement in the axel way. All these movements can be produced lonely (theoretic) and associated, mostly. To the 12 ways of movement are associated also 12 limited ways of movement,

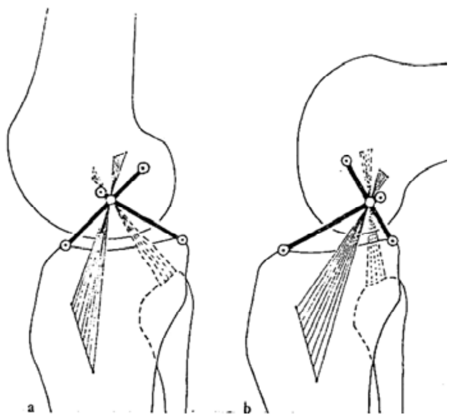

Fig. 8. The Menschik mathematical model

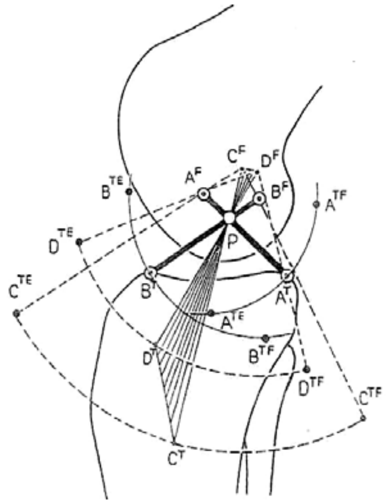

Fig. 9. The Menschik mathematical model

The ligaments length is a condition for the amplitude articulation movements, any extension or damage causing laxity apparition. The ligament tension represents an essential basic element of the ligament isometric. In this way the amplitude of movement is controlled for the developed tension to resist to mechanical charge.

ACL has like all the ligaments permissive, restrictive and movement guiding functions. The last two are practised with a tensioned ligament. All is in a close correlation with the other articulation structures.

The anterior-posterior translation depends on ACL length and integrity. When ACL is injured its length will increase when resting, with this the anterior tibial translation also.

The maximum anterior translation amplitude is near 30 degree in flexion, these dropping to 90 degree progressive. An intact ACL is the only structure which limits the tibia anterior translation to 30 degree. Once ACL is damaged the grade of translation depends on the movement amplitude which will tension the rest of the ligament or will stop the translation by the other structures, in complete rupture, when ACL do not participate to limit the anterior tibial translation.

In the rotation movements, ACL interfere in the internal rotational tibial movements by limitation.

The maximum anterior tibial translation amplitude is obtained for a specific grade of flexion with tibia in an indifferent position, but decreased when tibia is an internal or external rotation due to the extraarticular structures tensions.

The knee is characterised functionally by a great stability and mobility. These knee characteristics are given by specific knee anatomic elements and are resulting from passive elements, as well as active elements. In classical anatomy is considered that the stabilizing elements of knee are collateral ligaments and cruciate ligaments, but has found out that during instabilities sometimes it is not enough to treat only the ligaments for stabilising the knee, the surgery stability been more complex.

Summarising, exist two knee stabilising systems:

1. **Internal stabilising system:**
   - Internal collateral ligament
   - Anterior cruciate ligament
   - The antero-internal and postero-external capsule
   - The internal condyle surface
   - The internal meniscus posterior corner.

2. **External stabilising system:**
   - External collateral ligament
   - Posterior cruciate ligament
   - The postero-external capsule
   - The external condyle surface
   - The external meniscus posterior corner
   - The popliteus tendon.

It can speak about a posterior and an anterior compartment, which at their turn are divided in an internal and external posterior compartment and an internal and external anterior compartment, all of them separated by a central pivot made from the two cruciate ligaments. The principal role of the two stabilising systems (internal and external) is to prevent the abnormal femur-tibial movements.

The internal compartment elements oppose to the internal femur-tibial opening (valgus) and to the external rotation. The external compartment elements oppose to the external abnormal opening movement (valgus) and internal rotation. Both compartments and ACL prevent the anterior tibial sub spain on femur. PCL prevent the posterior tibial sub spain on femur.

The physiological movements control is given by PCL and posterior capsule formation which limits tibia extension on femur avoiding the recurvatum and the external tibial rotation on femur which appear with the knee in flexion and is controlled by internal compartment elements with ACL at maximum tension (40 degree rotation) and internal tibial rotation on femur controlled by external compartment and ACL (30 degree rotation). The stabilisation in one only plan is made by anatomical different structures.

The anterior-posterior sagittal plan is the movement plan with flexion-extension maximum amplitude stabilised by cruciate ligaments and flexor-extensor antagonic.

The frontal plan includes a medial and lateral stabilising system (collateral ligaments, capsule, etc.). In normal conditions are not movements in this plan.

The horizontal rotation plan is stabilised by the anti torque-torque system written above.

The anterior-posterior stabilisation is assured by the central pivot formed from ACL and PCL:

- The posterior ligaments compartment include the internal and external capsule lateral parts and a central part which represents capsule duality of the oblique popliteus ligament and the curve popliteus ligament;
- The anterior ligament compartment constitute from the patellar ligament connected with the vasti lateralis through the patella.

The extension-flexion physiological is assured by the central pivot and extension apparatus. The central pivot guides the both condyles move on the tibial plateau, assuring a perfect femoral-tibial guide by permanent tension changing, due to the fibres disposition, existing in the same moment tensioned and relax fibers. In complete extension, both cruciate ligaments are tensioned, the extension engine and the flexion stabilizer is the quadriceps muscle.

Stabilisation in frontal plane

It shows that exist an internal and external stabilizer system. In these compartments could distinguish, from inside to outside, only one capsule plan, a ligament and muscle – tendon plan. The capsule plan is closed to menisci and suffers thickening at meniscus-femoral level and to menisco-tibial level. In a study about these compartments are differentiated three sections, referring to the horizontal anterior, medial and posterior plan. In the anterior third the relation between internal and external structures are identical. Capsular ligaments are confounded with retinaclus of the quadriceps extension apparatus.

In the medium third the capsule ligaments are resistant and strengthen the internal collateral ligaments and iliotibial tract. In the posterior third both compartments have notable differences. If the internal compartment has the articular capsule thickened, forming the internal condyle capsule and oblique popliteal ligament with dynamic stabilizer base semitendonous, external compartment I compound from the external collateral ligament, the arcuate popliteal ligament and the tendon of popliteus muscle. The result is increased by the dynamic stabilisation of the biceps femoris and popliteus.

Physiological the knee suffers important actions in frontal plan neutralised by the articular morphologic surfaces, menisci and the stabilisation formations mention above. The most efficient action of these formations manifest in complete extension, and in flexion of 10 and 30 degree is progressive relaxation and appear a small physiological medial and lateral laxity. Rotational stability is controlled by the majority of active and passive stabilisation elements. The axial rotation is present in sports with directional changes, most frequent, with abduction/adduction of knee in easy flexion. The physiology in complete extension is given by the rotation movement absence due to the perfect congruently between the articular surfaces and all the ligament tension. In flexion the rotational flexion is assured by the active and passive formations:

- the posterior third of the internal stabilising system structures;
- the internal meniscus posterior corner ;
- the internal condyle surface,
- the internal collateral ligament;
- P.C.L. for extern rotation of the tibia on femur and the posterior third capsule;
- the extern stabilising system;
- P.C.L. together with the external collateral ligament forms a true antirotational complex and active tensor fasciae latae muscle and biceps for internal tibial rotation on femur.

Conclusions

In conclusions the stability of knee depends on an only one ligament or structure, but depends on a complex of active and passive structures determined by movement. The damage of one ligament does not create from the beginning a functional instability, its function being compensate by the others synergetic structures, but for long or shorter time, after decompensation appear. Knowing these elements, we can put the exact diagnose which result following the examination of all these morphofunctional elements which are assuring the knee stability.

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Studiu clinic şi imagistic asupra biomecanicii genunchiului

Rezumat

Anatomia şi fiziologia genunchiului suferă importante solicitări în plan frontal, sagital (antero-posterior), plan orizontal de rotaţie neutralizate de morfologia suprafeţelor articulare, meniscurilor şi formaţiunilor de stabilizare antero-posterioară şi în plan frontal datorată congruenţei perfecte între suprafeţele articulare şi tensionării tuturor ligamentelor prin sistemul stabilizator intern şi extern, ruptura unui ligament nu creează de la început o instabilitate articulară, funcţia lui fiind compensată de celelalte structuri sinergice pentru un timp mai lung sau mai scurt după care apare decompensarea.

Pentru o mai bună înţelegere din punct de vedere al biomecanicii şi reeducării funcţionale ambulatorii după chirurgia genunchiului, lucrarea tinde să explice gradele de mobilitate în flexie şi extensie determinate de ligamentele încrucişate, rolul stabilizator al ligamentelor în cadrul complexului lanţ cinematic al genunchiului, mecanismul pârghiilor încrucişate, modelul matematic Menschik de izometrie al ligamentului încrucişat anterior pentru articulaţia genunchiului şi leziunile ligamentare privind instabilităţile genunchiului, stabilizarea operatorie fiind mai complexă iar perioada de recuperare mai scurtă.