ANATOMICAL AND BIOMECHANICAL STUDY OF INJURIES OBSERVED DURING EXPERIMENTAL PEDESTRIAN-CAR COLLISIONS

by

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Within the compass of our Biomechanics Impact Laboratory, set up by the Anatomy Laboratory of the Medical School (Faculté de Médecine, in French), the National Body for Road Safety (Organisme National de Sécurité Routière, in French) and Citroën, the automobile construction company, we have drawn up a protocol of experimentation, with an eye to improving pedestrian safety.

Our aim is, by means of studying the results of impacts inflicted upon pedestrians by vehicles, to lessen, as far as is possible, the extent of the damage that they can cause the pedestrian, by modifying their form and structure.

The global analysis of all experiments carried out has enabled as to break down the progression of the accident into three stages :

- the first phase of the impact was when the bumper came into contact with the lower limb, and the bonnet of the car came into contact with the pelvic belt.
- the second phase of the impact was when the bonnet and the windscreen came into contact with the head, body and limbs of the subject, thrust upwards by the impetus of the impact.
- the third phase of the impact was when the head, body and limbs came crashing down onto the ground.

The report presented here, only takes into account the data concerning the first phase of the impact, which took place at a low height i.e. from below the middle part of the thigh downwards. Injuries to the pelvis (there were six reported cases) and to the hip (two cases reported) have been excluded from this report : those injuries were generally due to fierce contact with the bonnet.

Two reference positions of the subject in relation to the vehicle were adopted :

- in the first position, the subject received the impact from the front and we can say that the two lower limbs were hit almost simultaneously.

- in the second position, the subject received the impact from the side. Here the two lower limbs were involved successively, as the right lower limb transmitted the impetus by smashing into the left lower limb.

I - MATERIAL AND METHOD

The location of the contact between the lower limb and the bumper in the first phase of the impact was the frontal left third of the car, at a height of between I8 and 22 inches from the ground.

The vehicle was set in motion by the use of a launching ramp. Three types of vehicles were used to obtain these results and they will not be named here separately.

The speeds used were 6 I/4, I2 I/2, I5 I/2, 20 and 24 I/4 miles per hour.

The subjects used for experimentation were fresh corpses which had been made supple for the tests. Close examination of the progression of the impact was made possible by the fact that we took photographs and filmed the experiment at 500 frames per second. The corpse underwent a full medical examination, X-rays and a complete necropsy after the simulated accident.

Our study is based on the observation of 30 frontal impacts, which risulted in 23 injuries and the observation of 28 side-on or lateral impacts, giving 2I injuries. The absence of any injuries to the lower limbs in some cases is explainable by the adoption of slow speeds and lightly-built subjects.

II - APPLIED ANATOMY

In order to fully understand the type of injuries produced and the classification that we propose to use, it is absolutely necessary to remind yourselves of several definitions of fonctional anatomy and biomechanics :

- Let us begin with the femur, a bone of support like a beam which serves as a muscular attachment. It is a reinforced compound beam.

- The knee is composed of many parts :

The femur, which serves as a muscular and ligamentary attachment and carries two connected condyles of different vadii. (the way in which the two condyles are connected makes this joint lose one of the two planes of mouvement and bending involves a certain rotation because of the different radius).

The patella, which acts as an intermediary, directing the movement of the anterior muscles.

The tibia, which offers muscular and ligamentary attachments, two glenes, depened by two menisci and lengthened behind by two receptive posterior discs.

The ligaments, which support the lateral muscles, which assure the statics and dynamics of the joint.

- The tibia is a beam bone, serving as a muscular attachment. It is a compound beam.

- The fibula or splint bone has practically no use apart from being the lower attachment of the external lateral ligament. It has muscles and intervenes at the level of the heel joint by means of the malleolus.

The statics of the lower limb demands the unisson of the slightly angled, lengthening movement of the femur with the tibia ; the joints, condyles and glenes are strengthened by the lateral and crossed ligaments and by the peri-articular muscles. The system of reinforcement allows the knee to bend backwards more than I20° and enables a slight rotation to take place. It is difficult to reconstitute, as it demands intra-articulary surgery on fibrous tissues, adding the elements which entail a high risk of failure.

III - PROGNOSIS-REMARKS CONCERNING THE HEALING OF INJURIES

When it is a matter of simple ligamentary injuries or simple fractures of a beam bone, a simple prognosis after the treatment is sufficient. On the other hand, if it is a question of a fragmentary break, there is the risk of pseudarthrosis, if the ligamentary injuries are complex.

Incomplete treatment would lead to the instability of the knee whereas complete treatment would entail a delicate operation to transpose the tendons, with serious immobilisation and reeducation as a result. All things considered a conventional bone injury is more easily treated by a surgeon than a ligamentary one. Looking at the question from the point of view of seventy, the ligamentary injury, although less "spectacular" often results in a more intense and lengthy period of incapacitation.

IV - THE DIFFERENT TYPES OF INJURIES DISCOVERED

We have been able to group the injuries, which were extremely polymorphous, into two main categories :

- Type A denotes the type of injury resulting from an indirect mechanism, the force of the impact having made contact at a distance from the actual injury.

- Type B denotes the type of injury, resulting from a direct mechanism, the break being at the precise point of contact or in the immediate vicinity.

The type of injuries classed in Type A are those concerning :

- the ligaments (one or several may be involved) which are either pulled or torn.

- the bones (one or several) when the tearing off of a ligamentary or muscular attachment is involved. It may be accompanied by an injury, characteristic of buckling and resulting from the crushing and telescope-like compression of the spongy bone.

We can find type A injuries in the region of the femural condyle, the head of the fibula, the tibia spines, the interglenoid cavity (the central pivot of the knee) the patella and the tibia plane in the area of the margo infra glenoidalis.

We have called the type A kind of injury, where the two legs have been involved, group Ax2, and the combination of a type A fracture and a uni or bilateral type B injury, group AB.

Type B injuries : under this neading we find simple or fragmentary fractures, found in the region of the collar, the diaphyse or the lower extremity of the fibula, the diaphyse or the lower extremity of the tibia and the two bones of the leg, which is horizontally broken in just one or several places.

We have called the type of injury where the two legs are involved, group Bx2, and the combination of these fractures with type A indirect injuries group AB.

V - RESULTS-ANALYSIS

We find that our deductions differ according to whether we have frontal or side-on impacts in mind.

- Let us first consider the results gained from frontal impacts. We discover a type A injury in 2I cases out of 23,4 of which were accompanied by a fracture. In two cases it was a matter of a single break. Fractures only started appearing from impact after 20 miles per hour.

Most of the indirect type injuries seem to be due to the increase of the surface of impact which lessens the force. But the ligamentary injuries, in particular involving the posterior discs, were very serious, because of the anti-physiological thrust of movement during the anterior bending of the knee when it came into contact with the convex form of the bumper.

- In side-on impacts, we discover that out of the 2I injuries observed, fractures were much more frequent than when the impact was from the front. (there were three cases of single fractures and twelve cases of fractures combined with type A injuries).

Fractures started appearing as a rule from the speed of I5 I/2 miles per hour upwards (apart from five exceptions), and were usually accompanied by ligamentary injuries.

We have attempted to pin down some general rules from our experimentation, consisting of fifty-eight simulated accidents. These remarks only count for the injuries caused upon the lower limbs below the thigh.

The recurrence and the severity of the injuries increase with acceleration.

Our experiments have shown that bones break almost systematically when hit from the side at I5 I/2 miles per hour, whereas at 20 miles per hour when hit head-on.

The plotting of the severity of the injury against the speed of the vehicle on a graph reveals that the most frequent injuries :

- in frontal impacts are type Ax2 ones, in other words, involving both legs,
- in side-on impacts, they are type AB ones and ones involving both legs. Therefore at an equal speed, the injury inflicted by a side-on impact is more serious than that by frontal impact.

But two notions which appear fundamental to us must be underlined here :

- The first concerns the notion of the seriousness of the injury : at I5 I/2 miles per hour, or above, a type A ligamentary injury may well be more difficult to both treat and heal than a regular break.

- The second concerns the transmission of the impetus within the accident victim itself. Here we have the problem of the transmission of the impetus after the impact from a beam bone to the rest of the body. Is it not true that an immediate straight break would considerably reduce the force of the movement during the second phase of the impact, when the head crashes into the windscreen and thereby cause far less serious physical damage ?

So, it is interesting to compare these experimental injuries with real ones. In this way we studied thirty-three injuried pedestrians, having a total of one hundred and fourty one injuries.

Biomechanically, it is very difficult to make such a comparizon, because there are few informations about the precise course of the crash, the exact position of the pedestrian (facing on, in profile or being on three-quarters) and, above all, about the speed of the vehicle.

When the impact occured, whereas they are very well know experimentally. Yet, there are many interesting points :

- first, the results of the primary shock are comparable ; on the lower limb, the same type of bone and ligamentar injuries can be found concerning the knee area, with the same percentage : on dead body, seventeen per cent fractures and nineteen per cent on pedestrian.

But we can notice that in a true accident, foot fractures occur in three per cent cases ; those are not found on dead body : it could be due to a difference of the kinematics after the shock.

That is confirmed by the other comparable injuries :

<u>On dead body</u> :

- seven per cent of skull fractures,
- twenty-six per cent of rib fractures,
- only one half per cent of upper limb fractures.

<u>On pedestrian</u> :

- one per cent of skull fractures,
- seven per cent of rib fractures,
- eight per cent of upper limb fractures.

Obviously the upper limb is used to protect skull and thorax, and so it is more injured.

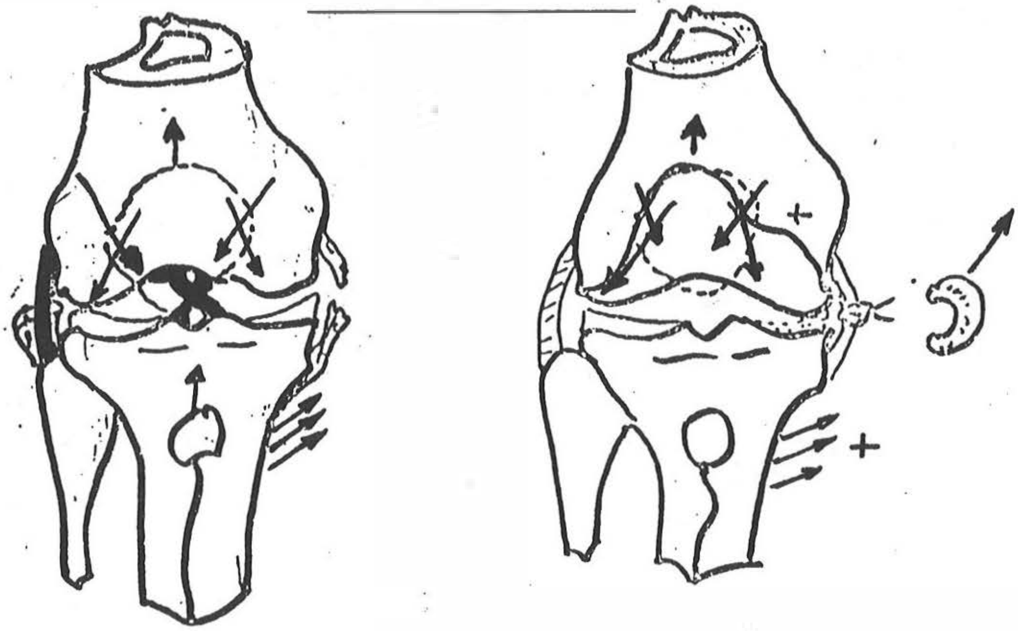
This is not a final noting, because we do not know the impact speed ; this does not allow to superpose the kinematics after the shock.

Nevertheless, the injuries caused by the primary shock are due to the same mechanism.

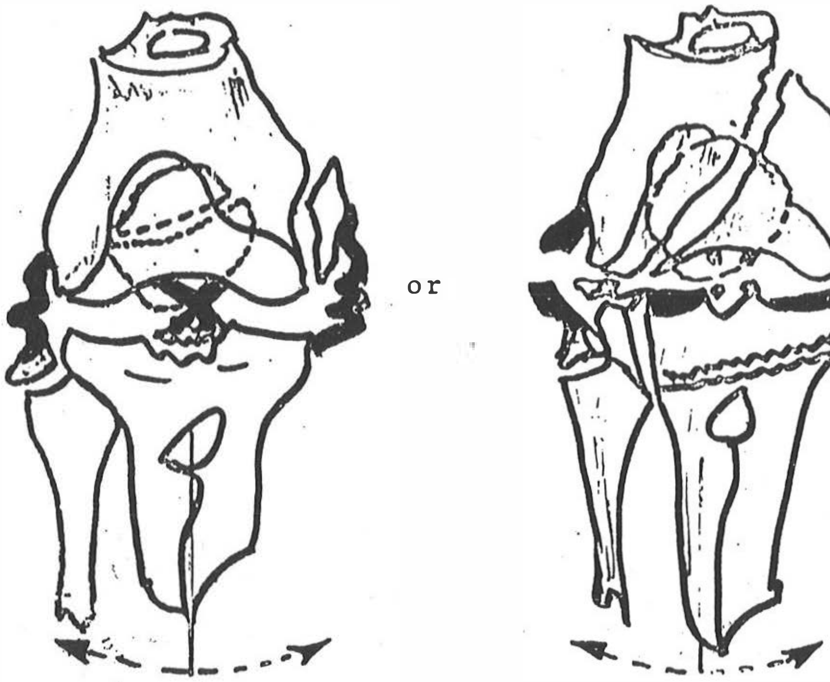
In this way, each development which has been experimentally satisfactory, will be beneficial when real crash.

A P P E N D I X

L I G A M E N T S



SIMPLE INJURY ——▷ GOOD PROGNOSIS



or

! ? Treatment more Difficult

MULTIPLE INJURIES

P R O G N O S I S

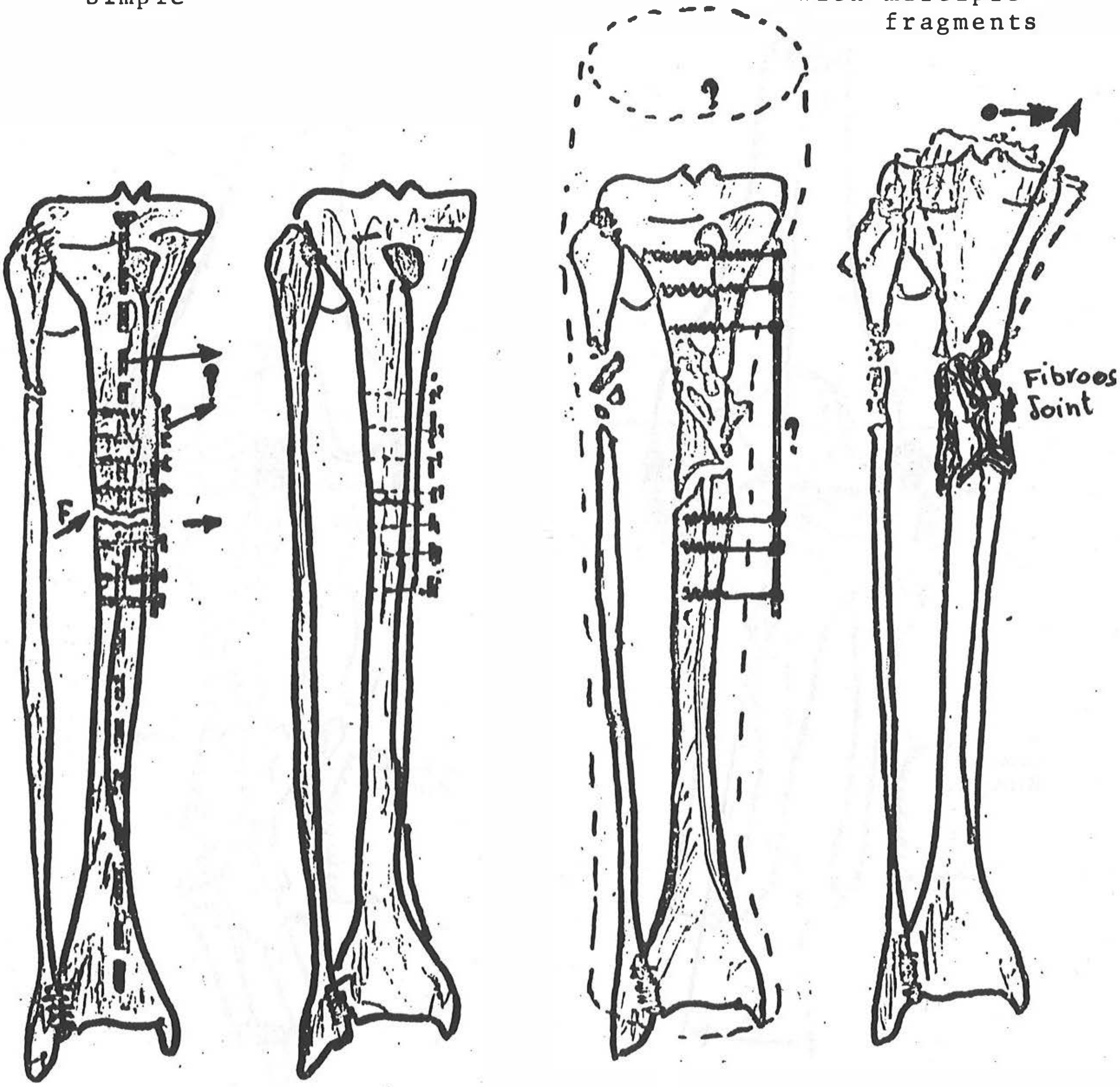
OS - POUTRES

BEAM - BONES

FRACTURES

Simple

With multiple fragments



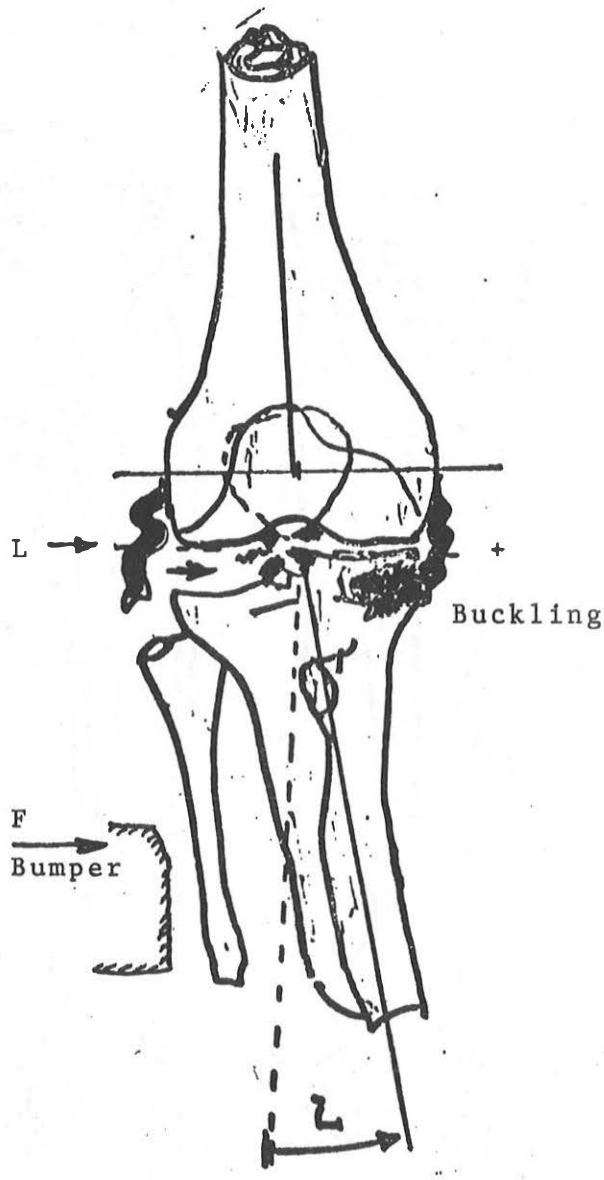
STEADY

UNSTEADY

PROGNOSIS

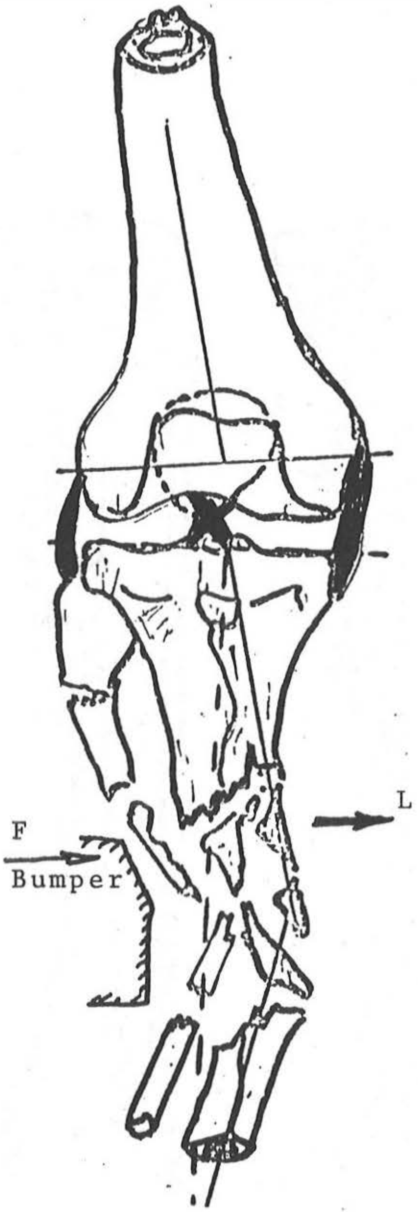
D I S C O V E R E D   I N J U R I E S

INDIRECT MECHANISM

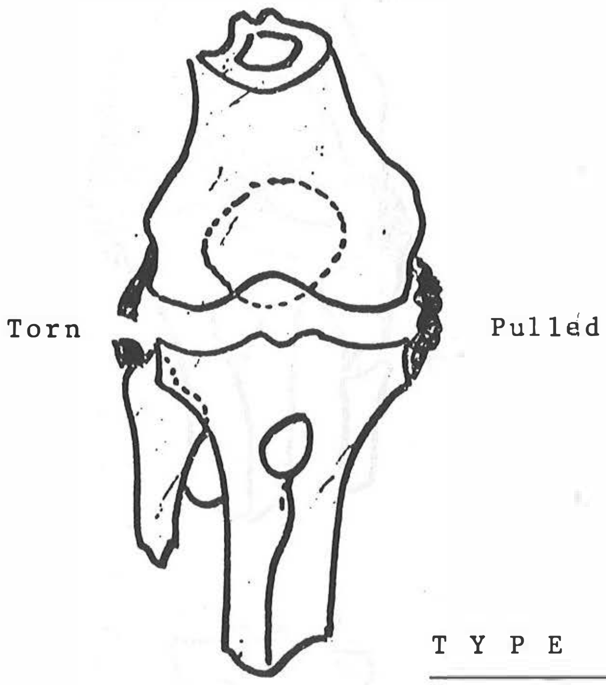


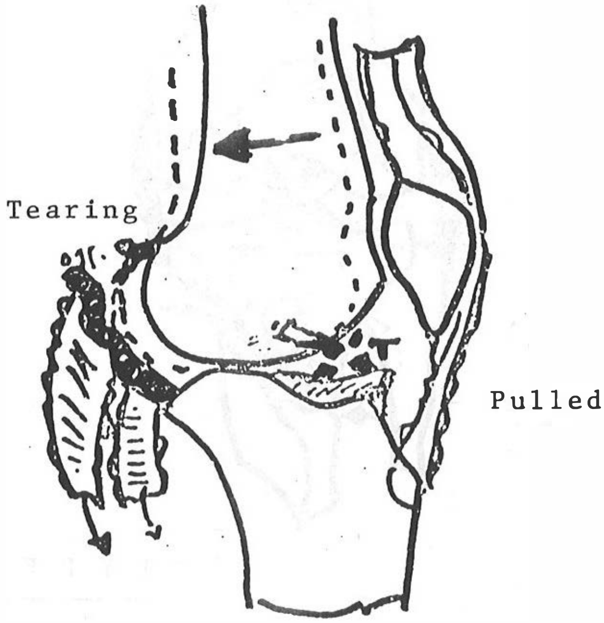
T Y P E   A

DIRECT MECHANISM



T Y P E   B

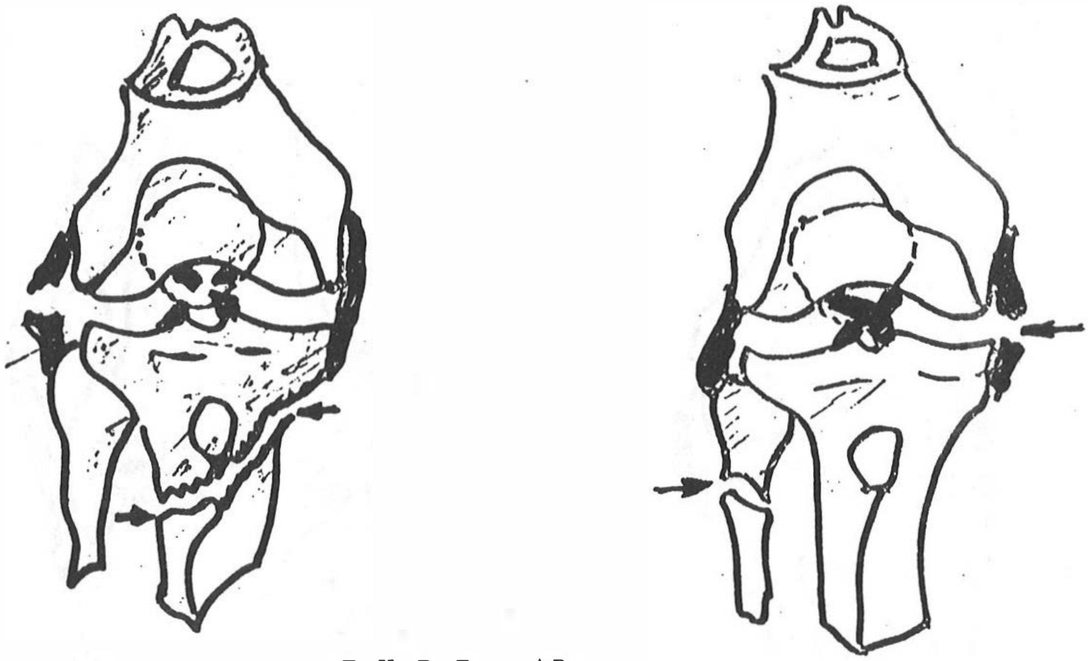




TYPE A

Tearing off
of an attachment

Idem with buckling



T Y P E   AB

T Y·P E   B