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EXPERIMENTAL KNEE-JOINT FRACTURES

A Preliminary Report

By

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INTRODUCTION

There have been many previous studies relative to experimental fractures and dislocations of the knee-joint (1–8). With the exception of recent work by Kennedy, the full results of which have yet to be published there has been relatively little experimental work that has attempted to determine whether fractures can be produced that correspond to known compressive forces. The present study is designed to accomplish this purpose.

MATERIAL AND METHOD

The study was performed on knee joints obtained at autopsy from 32 subjects who were free of disease known to affect the skeletal system. They were tested fresh or after freezing at —20° C for less than one month. Frozen specimens were tested immediately after thawing. The specimens consisted of the knee joint, and about 15 cm of the extremity above and below the joint, from which the skin, subcutaneous fat and muscle had been removed. The subjects ranged from 38–84 years, with a predominance in the 60–80 year group. There were 13 males and 19 females.

In order that the specimens could be held in position during the experiments the diaphyses were embedded in metal boxes in Plastic Padding A. The desired amount of knee joint flexion could be set and controlled at any desired amount during embedding by a specially designed apparatus (Fig. 1). The specimens were then transferred to a hydraulically powered machine, where they were loaded progressively from 0 at a rate of 100 kg/min. (Fig. 2). Load and distance between the loading and supporting heads were recorded by a kymograph (Fig. 3). When the curve that was being recorded showed signs of flattening or reversal, the experiment was discontinued. Often the sound of fracture could be heard at this point. The specimen was then removed and dissected for determination of the damage. A–P and lateral roentgenograms were taken before, during and after the experiment. After completion of dissection, the specimen was sliced with a band saw in the sagittal or frontal plane, depending on the fracture. Each slice was inspected and radiographed.

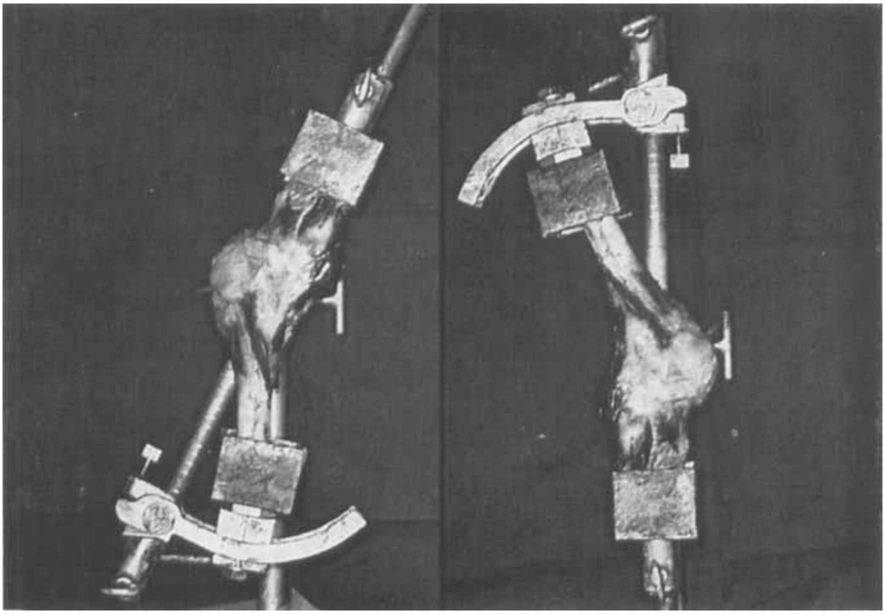


Fig. 1.
Apparatus for embedding the specimen in Plastic Padding. The box at the end of femur can be moved along the curved metal fork until the required angle of the knee joint is obtained. The whole preparation can be rotated through 180° to enable the other box to be filled with Plastic Padding without disturbing the adjustment in the joint.

RESULTS

The injuries that were produced fell into three categories—Bony; Ligamentous; or None. There was no case in which bone and soft tissue injury were combined. Four specimens had no definite sign of injury. In three, there were injuries of the posterior cruciate ligament and in one specimen, the lateral meniscus was ruptured. Fracture of the femoral condyle was seen in two cases, and in one of these, the fibular head contained a small fracture. The tibia was fractured in the remaining twenty-two cases.

The tibial fractures were divided into four groups. The first (3 specimens) demonstrated compression of the spongiosa approximately one cm below the articular surface. These fractures were not seen clearly on the radiographs, but they were visible when the specimens were being sawn. They were termed subcortical compressions, and they occurred at flexions greater than 20°, and at a smaller load than was

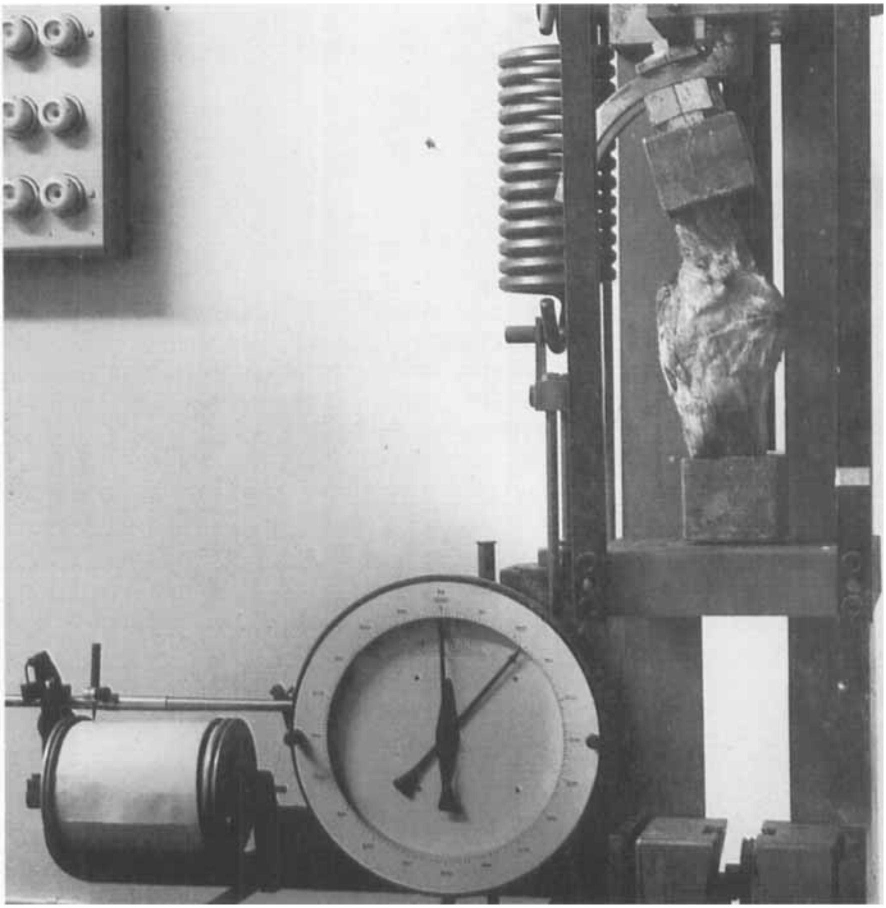


Fig. 2.
The specimen mounted in the testing machine.

required to produce the other types of fracture (Table 1). The second group (6 specimens) demonstrated depression of either one or both tibial condyles (Fig. 4). The third group (12 specimens) included fractures of a more severe nature, often sagittal in direction, and originating at or near the intercondylar area and running toward the medial or lateral aspect of the tibia. These were referred to as split fractures (Fig. 5). The fourth group consisted of four severely comminuted fractures (not included in Table 1).

It can be seen in Table 1, that pure split fractures were usually produced with 20° of flexion or less. Greater angles than this, usually pro-

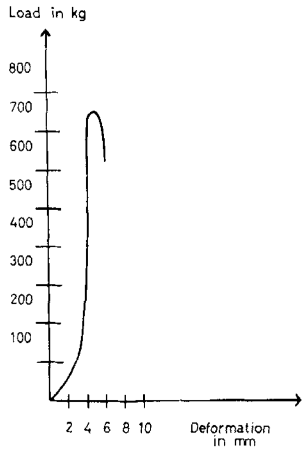


Fig. 3.
A curve obtained in a loading experiment on the knee joint. The ascending part occupies about seven minutes, whereas the descending limb, which represents loading of the already fractured joint, covers a few seconds.

TABLE 1

Various Types of Fractures of the Tibial Condyles Produced with a Varied Load and the Knee Joint Flexed.

Age	Sex	Flexion (°)	Load producing compression of sub-corticalis (kg)	Load producing depression of condyle (kg)	Load producing split fracture (kg)
44	♂	0			780
63	♂	0			1070
74	♂	0			1030
68	♂	5			720
79	♀	5			1010
63	♀	5			440
60	♂	15			980
74	♂	15		730	
81	♂	20			490
84	♂	20		735	735
70	♂	25		750	750
79	♀	25	325		
50	♀	30		500	510
60	♂	30		500	
38	♂	30		510	
82	♀	30	280		
58	♂	35			490
		55	360		

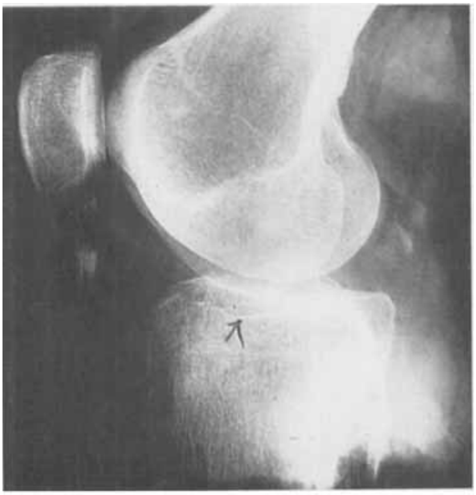


Fig. 4.
Lateral view. Depressed lateral condyle of the tibia. Woman of 50. Flexion 30°. Maximum load 510 kg.

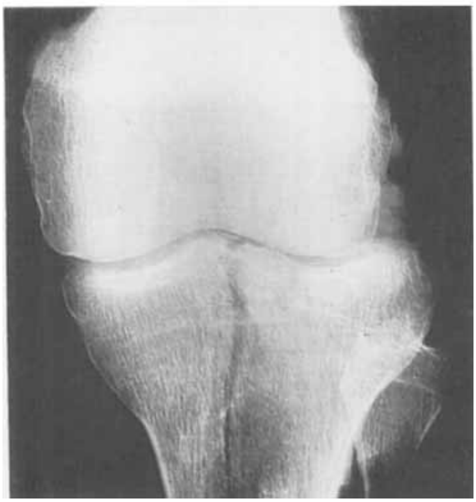


Fig. 5.
Anteroposterior view. Split fracture. Man of 44. Knee joint in extension. Maximum load 780 kg.

duced depression of the tibial condyle which was accompanied by split fracture in 3 cases. The cases with subcortical compression and soft tissue injuries were produced with flexion angles greater than 20°. No further relation between degree of flexion and type of injury could be determined.

Fractures were produced with loads ranging from 280–1070 kg. There was a tendency for fracture load to be greater fwor an extended knee than for a flexed knee (Table 2), but no statistically significant

Fig. 6 a.

Fig. 6 b.

Fig. 6 c.

Fig. 6 d.

Fig. 6 a. Compression experiments at 30° flexion. Woman of 50. Load 250 kg. No fracture.

Fig. 6 b. Load 480. The lateral tibial condyle of the tibia is depressed.

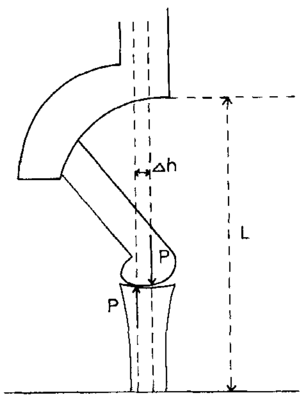
Fig. 6. c. Load 510 kg. The depression is increased. A split fracture has occurred and the medial fragment of the tibia has been dislocated.

Fig. 6 d. Load decreased to zero. The fragment has been reduced spontaneously.

TABLE 2

Mean Load for Various Types of Fractures. Relation between Angle of Flexion and Load at which Various Types of Fractures Occur.

0° — 20°	800 kg
> 20° (subcortical compressions excepted)	550 kg
subcortical compressions	320 kg



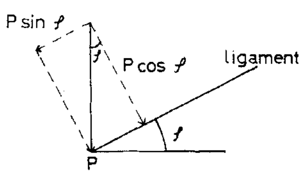


Fig. 7.

An attempt was made to analyse the moments. If the lines of action of the upper and lower compressive force *P* do not coincide, application of the force may result in a bending moment about the knee joint. With a distance Δ h between the lines of action the bending moment is P Δ h/2. If Δ h = 0 there will no bending moment until the critical point of buckling of *P* is reached. From this point P_k any further compressive energy is converted to bending energy.—P_k is given by the expression $\frac{EI}{P_k}.L^2 = 4\pi^2$, where E is the modulus of elasticity, I is the moment of inertia, L the distance between supporting heads. If this bending moment acts about the knee joint it will give rise to bending and compressive stresses, the magnitude of which is $\frac{M}{I}$. Z, where M is the bending moment and Z is distance from the centre of bending (positive or negative). However, these bending and compressive stresses act almost perpendicularly to the ligament and are primarily taken up in normal flexion of the knee joint. Any component in the direction of the ligament cannot be determined accurately. On the other hand, the ligament forms an angle φ with the (horizontal) articular surface. If it is assumed that *P* is taken up at the attachment of the ligament, the component P cos φ should constitute the compressive force on the bone (and any rotation of the ligament), while the component P sin φ (that is the force T) stretches the ligament. For a rupturing force p of 700 kg the stresses on the ligament for some practical values of flexion will be as follows:

φ	0°	5°	10°	20°	30°
sin φ	0	0.087	0.174	0.342	0.500
T(kg)	0	60	120	240	350

differences could be determined between load and type of fracture or load and amount of flexion combined in producing fracture.

Soft tissue injury was produced in the 300–700 kg range. There are several possible explanations for soft tissue injury in this type of experiment, one of which is indicated below. In four cases, no injury was seen, although the curve appeared to flatten in the usual range. This can be the result of premature cessation of the test or submicroscopic damage.

From a series of anteroposterior radiographs taken in an experiment, in which both depression and split fracture was obtained it was evident that depression occurred first (Fig. 6). The last two radiographs of the series showed that when the load was decreased to 0 the dislocation of the fragments was reduced.

The difference in load between flexion and extension causing lesions may possibly be ascribed to (i) the decrease in the area of contact as the angle of flexion is increased resulting in an increase in the load per unit of area, because of the shape of the femoral condyles, (ii) a change in the action of the intra-articular forces from the cruciate ligaments, and (iii) differences in the moments at the critical point of buckling for different angles of flexion (Fig. 7).

SUMMARY

A method producing intra-articular injuries in autopsy knee-joint specimens is described. Only vertical loading with differing flexion angles of the knee has so far been studied. Most of the injuries were fractures and occurred in the tibial condyles. These were of three types: subcortical compressions, condylar depressions and split fractures.

The type of fracture of the tibial condyle appeared to be dependent on the angle of flexion. Angles exceeding 20° produced first condylar depression and then a split fracture. Extension resulted in split fractures. The load required to produce a fracture tended to be greater for the extended than the flexed joint.

RESUME

Il est décrit une méthode pour produire des lésions intra-articulaires à l'autopsie de spécimens d'articulations du genou. Jusqu'ici, seule une charge verticale avec différents angles de flexion du genou a été étudiée. La plupart des lésions étaient des fractures du condyle tibial. Celles-ci

étaient de trois types: compressions sous-corticales, dépressions condylaires et ruptures osseuses.

Le type de fracture du condyle tibial est dépendant de l'angle de flexion. Les angles dépassant 20° produisent d'abord une dépression condylaire, puis rupture. L'extension provoque une rupture. La charge requise pour produire une fracture de l'os est plus forte pour l'articulation en position d'extension que pour celle en position de flexion.

ZUSAMMENFASSUNG

Eine Methode, die intraartikuläre Schäden an Autopsiepräparaten des Kniegelenkes hervorruft, wird beschrieben. Nur vertikale Belastung mit verschiedenem Beugewinkel des Kniegelenkes ist vorläufig studiert worden. Die Mehrzahl der Schäden waren Brüche, die in den Tibiakondylen entstanden. Es traten drei verschiedene Typen auf: Subkortikale Kompressionen, kondyläre Depressionen und Spaltungsbrüche.

Die Bruchtype des Tibiakondyles schien vom Beugungswinkel abhängig zu sein. Winkel über 20° erzeugten erst kondyläre Depression und dann Spaltungsbrüche. Extension ergab Spaltungsbrüche. Die Belastung, welche man zur Hervorrufung eines Bruches verwenden musste, war im allgemeinen grösser bei gestrecktem als bei gebeugtem Gelenk.

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