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The mechanical function of the meniscus, experiments on cadaveric pig knee-joints

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From experiments of, for example, Krause, Kettelkamp, Blaimont, Maquet and many others, it has become clear that the menisci have an important function with respect to the load carrying capacities of the knee. It was the object of our research programme to evaluate in which way the material and geometrical aspects of the menisci and the surrounding structures like joint cartilage, subchondral bone and ligaments influence the mechanical behaviour, the load transmission, in the knee.

Pigs knees were chosen for the experiments, because of their availability and the assumed pronounced function of their menisci. The joint was regarded as a non-linear, visco-elastic mechanical system. This system was subjected to different loading types in a specially developed experimental setting in a Instron testing machine. The pigs knees were fixed in two plexiglass rings filled with acrylic cement. The rings were fixated in the experimental setting in such a way that only vertical movement was possible (fig. 1).

The mechanical system described on the right side was being subjected to different loading types. The transient response of the system, being either displacements or reaction force, was measured. The different kinds of loading functions were: slow and fast loading, repeated step loading and impact loading, carried out on the intacts knees and repeated after meniscectomy.

For instance in a fast loading case we applied a constant deformation rate of 0,3 cm/min, which resulted in a displacement between pins on either side of the joint line; while the progressive loading was registrated (fig. 2).

We are in the process of developing a rheological model, consisting of linear and non-linear springs and damping elements, related to the structures present. A draft of this model is shown in figure 3.
FIG. 1. — Schematic drawing of the experimental setting.

FIG. 2. — Displacement between the pins resulting from a fast loading with and without menisci.

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FIG. 3. — Rheological model of the displacements shown in figure 2.

FIG. 4. — Schematic drawing of system using X-ray photographs to measure the contact areas in the knee.
FIG. 5. — Load carrying area as a function of loading for two knees.

FIG. 6. — An example of a force response for a knee with and without menisci.

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The mechanical behaviour of this model has been simulated by means of the mathematical description of its mechanical properties in a computer. In addition to these transient loading experiments, the contact area in the knees were measured as function of loading, using X-ray pictures after insertion of barium-sulphate. The technique used was developed according to the one described by Ketelkamp and Maquet. The measurements resulted in interesting data with respect to the area enlarging function of the meniscus.

In figure 5 you see the load carrying area as a function of the loading for two different knees, medial and lateral side with and without menisci. These data were used in the model.

As mentioned before the knee was also subjected to impact loading. A 20 kg weight was dropped from a height of 20 or 10 mm on the knee. The response reaction force was measured (fig. 6).

In order to acquire insight into what really happens in the knee joint after impact loading, and in this way verifying certain assumptions made in the process of modelling, we made a high speed camera film of the joint during this loading procedure. This film proved to give much interesting information.

As preliminary conclusions from this research work, it can be stated:

1. The menisci enlarge the load bearing area in the knee joint considerably, so that:

2. After meniscectomy the average contact stresses on the joint surfaces may become several times higher in normal functioning.

Of course, these facts were also established by other research work reported in literature.

From the high speed camera film we found that:

1. After meniscectomy the two joint parts show considerable kinematic behaviour on impact loading, even when these parts are fixed as rigidly as possible. These movements are damped by the ligaments, so that:

2. The knee without meniscus becomes unstable and:

3. The ligaments of a knee after meniscectomy are subject to "heavy duty" in normal physiological functioning. They will be frequently highly stressed and stretched, perhaps even into the plastic region.

4. Although the said kinematic behaviour makes it hard to interpret the transient responses of the loading tests, a rheological model of the joint with realistic physical elements can be developed.

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5. In such a model the function of the meniscus can be divided into two effects. A non-linear, but non-time dependent elastic effect, related to the circumferential stretching and a non-linear visco-elastic effect, related to the loss of a part of the weight carrying area.

To summarize, the menisci in the knee can be considered as contact area enlarging, weight bearing, stabilizing, non-linear springs.

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