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EXPERIMENTAL TESTS CONCERNING THE BIOMECHANICAL BEHAVIOUR OF PERTROCHANTERIC OSTEOSYNTHESES

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The biomechanical behaviour of pertrochanteric fractures stabilized by means of an angled plate or flexible condylar nails was characterized by mechanical testing. The stability and the types of motion occurring under dynamic load in the vicinity of the fracture and the effect on the implant were examined. The mechanical test results corroborated clinical experiences. In the case of extramedullary anchorage of implants, stability under load is possible only if an intact cortex on the medial side of the fracture guarantees the bearing of compressive load. With flexible condylar nails, however, it is possible to achieve a permanent load capacity up to approximately 100 kp, even if medial support is lacking, by putting the fracture in a valgus position so that the load-bearing arm is shortened.

It was also possible to estimate the actual loading on the operated leg within the immediate postoperative phase by means of the "stabilization effect".

Key words: angled nail-plate; biomechanical investigations; flexible condylar nail; pertrochanteric osteosyntheses

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The fate of old people with a pertrochanteric fracture of the femur mainly depends on the possibility of early mobilization of the operated leg under load. Therefore an implant suitable for the stabilization of these fractures has to withstand all forces arising under physiological stress within the area of the fracture and to guarantee stability under load until osseous healing of the fracture has taken place. The existence of a great variety of methods of osteosynthesis for the treatment of pertrochanteric fractures suggests that none of these methods is able to meet all requirements fully.

At present the implants generally used in osteosynthesis can be divided into two groups based on fundamentally different principles of load transmission:

1. Extramedullary nail and screw models (e.g. McLaughlin nail, Scheuba nail, 130° angle plate), the plates of which are fixed to the exterior side of the femur. The forces acting on the hip joint become effective on the metal itself, above all as local bending forces, which the implant alone cannot resist permanently. Through an exact reposition of the fracture, and with strong medial support, transmission of load to the bone is possible so that bending or breaking of the nail can be avoided.
2. Intramedullary nails (e.g. Lezius nail, Küntscher nail, Ender nail) are mainly loaded on their longitudinal axes. Therefore bending forces are not restricted to a small localized area and full advantage can be taken of the intrinsic flexibility and the

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statically and dynamically favourable design of the nail.

Since 1972 our hospital has been using very successfully the flexible condylar nails, as described by Ender & Simon-Weidner (1970), for the treatment of pertrochanteric fractures in patients past middle age, and in all cases primary load stability was achieved (Passl et al. 1975). In an experimental study we have examined the biomechanical qualities of this method of osteosynthesis and compared it with the 130° angled plate of the AO, which mechanically corresponds to be angled nail described by Scheuba (1971), which we had been using before (Martinek et al. 1976). Of special interest to us were the forces acting during weight-bearing in the immediate postoperative phase and the resulting deformation of the osteosynthesis.

MATERIALS AND METHODS

Our experiments were carried out on cadaver bones that had been removed 27 hours post-mortem. Three experimental groups were compared:

Group 1: In six femurs a pertrochanteric fracture running from the tip of the trochanter major to the trochanter minor was artificially produced with the oscillating saw and stabilized in the typical manner with three flexible condylar nails.

Group 2: In six femurs, prepared in the same way as those of group 1, the pertrochanteric fracture was stabilized by means of an angled plate.

Group 3: In five patients, who had died within 14 days after the fixation of a fracture by flexible condylar nails, the femurs operated on were removed and compared with those in group 1. This group was of special importance since the standardized experimental fractures of groups 1 and 2 with a smoothly cut surface and the presence of medial support did not fully correspond to fractures occurring *in vivo*.

As far as the true load capacity of an osteosynthesis is concerned the results of static measurements seem to be of little value since at cyclic loading, as in walking, the dynamic interplay of implant and bone determines the true load capacity. Therefore the experimental conditions were designed to resemble the physiological conditions under dynamic load as closely as possible. For this purpose we used a hydraulically operated static-dynamic "closed-loop" deformation machine (by Instron, England, Type 1253). An electronic control enabled loading tests which followed a dynamic loading programme, variable at choice, simulating the sequence of loading occurring in the femur during normal walking. The resolution of the power analyser was 0.05 kp and the resolution of the extension measurement 0.001 mm. The reproducibility of the values measured between different specimens (bones) was about ± 10 per cent; the error due to the experimental arrangement was 0.5 per cent.

In a specially constructed mounting the distal end of the bone was embedded in bone cement so that a punctiform supporting area, with the risk of crushing of the cortex layer, was avoided. The head of the femur was held in a ball socket so that free rotation of the head permitted deformation of the thigh bone. In this position we subjected the bones to dynamic loading cycles. The load rise time in our experiments was extended to 0.25 seconds, corresponding to the careful loading of the leg within the immediate postoperative phase (Martinek et al. 1976).

By recording the load deformation diagrams during the loading experiments the following data could be obtained:

1. The bending of the implant per step at a constant dynamic load amplitude, this being a measure of irreversible dislocation of the proximal part of the femur.
2. The number of loading cycles of a certain force which causes a lasting shortening of the distance femoral head – femoral condyle of 10 mm. In our opinion an irreversible deformation of the total length of the femur of more than 10 mm can be defined as an intolerable one since the resulting malposition affecting the entire hip joint would lead to considerable coxa vara.
3. Information concerning the physical behaviour of the implant (e.g. relaxation) was obtained by keeping the length of the femur constant during the experiments and registering the resulting decrease of load.

RESULTS

Group 1

There existed a direct relation between the magnitude of the applied force and the extent of the resulting deformation. At load values under 145 kp the deformation of the osteosynthesis material was almost negligible. A loading cycle with a force of 145 kp caused an irreversible shortening of the total length of the femur of 0.001 mm, so that about 10,000 steps were tolerated by these osteosyntheses until the deformation limit of 10 mm, as it was set by definition, was reached. An increase of the applied force to 180 kp resulted in an irreversible bending of as much as 0.1 mm per step, a value which cannot be tolerated with a load resisting osteosynthesis. At these load levels the limit of shortening of 10 mm was already reached after about 100 steps. A load of 210 kp led to the destruction of the osteosynthesis which repeatedly manifested itself in fracture of the medial cortex.

The type of motion under load in the vicinity of the fracture started with a sliding movement of the head fragment along the surface of the osteotomy under slowly increasing contortion of the flexible condylar nails until these nails rested on the medial support. With further loading, the head fragment rotated around this point until the cortical layer fractured in the area that supported the condylar nails as the breaking load (210 kp) was exceeded. But even then the osteosynthesis had a carrying capacity of

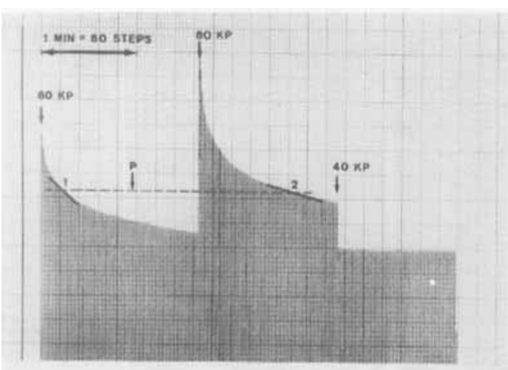

Figure 1. Cyclic loading of an osteosynthesis with constant total strain amplitude. The load decreases with every step due to plastic (i.e. irreversible) deformation. After application of a higher load, e.g. 80 kp, the additional plastic deformation proportional to the tangent at any reference load P is much less and is negligible for lower loads, e.g. 40 kp. "Hardening" has stabilized the osteosynthesis.

50–100 kp, depending on the size of the broken fragment.

The stabilizing effect, known in metal physics as "work hardening", was also observed in our experiments. It is characterized by a hardening of the implant according to the load applied, so that a further distinct irreversible deformation is to be expected again only under a higher load. The effects of this hardening are shown in Figure 1.

Group 2

In pertrochanteric fractures fixed by means of an angled plate a lasting shortening of the femur of 0.001 mm occurred already with a single loading of 120 kp. An increase of the load to 140 kp resulted in an irreversible deformation of 0.1 mm. An intolerable bending of the implant (= a lasting shortening of the total length of the femur of 10 mm) occurred at a load of 165 kp.

Under cyclic loading this osteosynthesis showed a type of motion in the vicinity of the fracture completely different from the fractures of group 1, fixed by flexible condylar nails. At each loading cycle some rotation of the head fragment round the pivot at the junction blade – plate took place (Figure 2). This results in a strongly localized tensile stress in the metal in this area which may lead to the clinically known fatigue fracture of the implant in this area (A in Figure 2 a), caused by alternating of the deformation load.

Group 3

The qualities of the osteosynthesis based on the laws of metallurgical physics and on the geometry of the implant correspond to the results of group 1. Only at the beginning of the loading, at load values of 30 kp, did significant "consolidation settlement" of 20–40 mm take place. This effect was not due to a reduced load capacity, but only after this loading was close contact of the ends of the fractured bone achieved. A subsequent loading of 90 kp resulted in a lasting shortening of 0.001 mm, and a loading of 110 kp brought about an irreversible deformation of

a
b

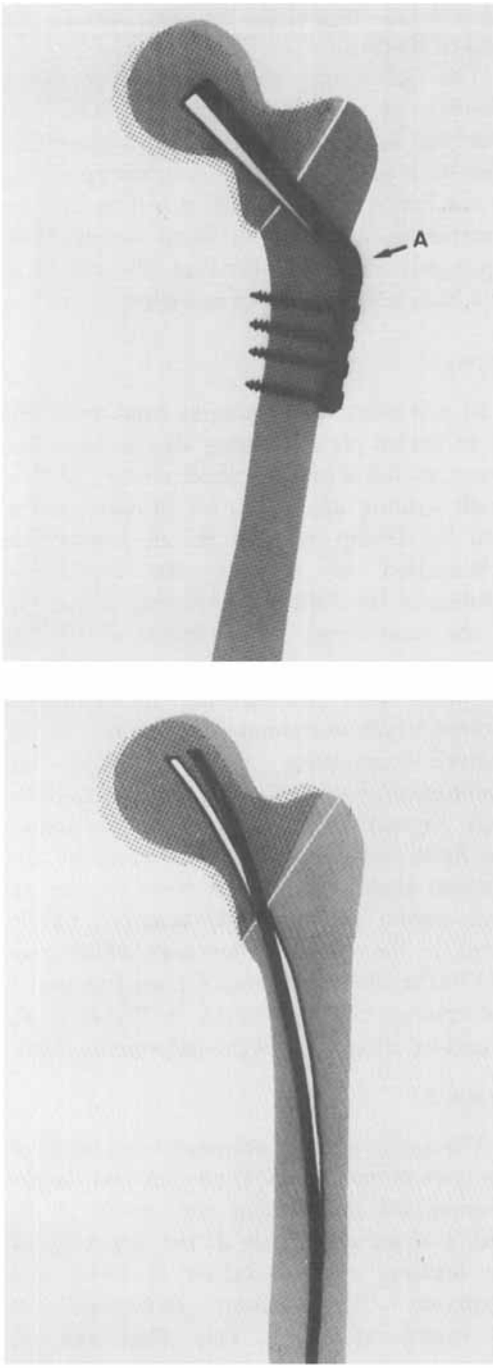

Figure 2. (a) Angled plate. Rotation of the femoral head around axis A. The strain is highly localized and sometimes fatigue fracture occurs at this point. (b) Condylar nail. The strain within the implant is distributed over a considerable length, therefore no localized stress occurs.

0.1 mm. A load of about 140 kp caused breakage of the osteosynthesis.

Out of this group, two patients had been able to walk well before they died and the operated leg had carried weight. As expected, the initial shortening at low values was lacking in these specimens since "consolidation settlement" of the osteosynthesis had already taken place due to the intravital loading. In these two cases an irreversible deformation of the implant could be seen only at load values of more than 80 kp. Taking into consideration the stabilizing effect described above, we may conclude that the extremity had already been loaded up to this value before the patient died. Intravital "consolidation settlement" of the fracture had already taken place and an irreversible deformation corresponding to a loading of 80 kp had developed.

In three patients the leg had carried no weight before they died. Figure 3 shows a

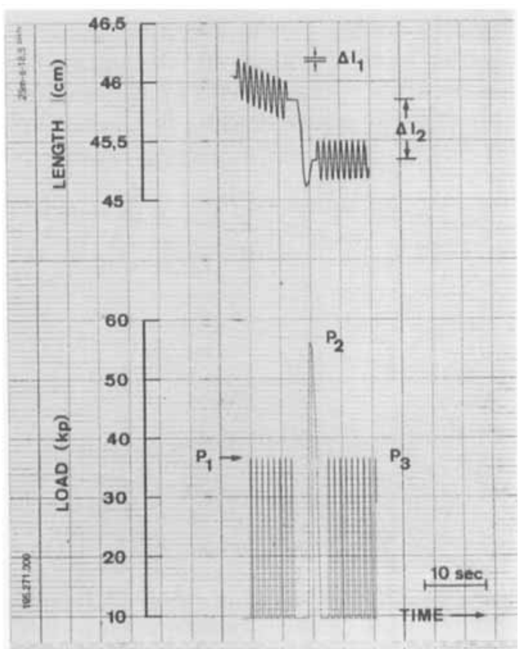

Figure 3. A direct recording of load vs. time and strain vs. time respectively. At P_1, every cycle (step) causes an irreversible shortening Δl_1 of the osteosynthesis. Loading up to P_2 brings about a stable osteosynthesis. At $P_3 = P_1$ ("stabilization effect") no further irreversible shortening is observed.

typical diagram of this group. The lower part shows the machine-controlled loading cycles (steps) adjusted to a certain value (P_1). Since the osteosynthesis is exposed for the first time to this load P_1, every step is accompanied by an elastic (reversible) shortening as well as a small plastic (irreversible) shortening $\triangle l_1$. A single overload (manually shifted to P_2) causes an irreversible shortening $\triangle l_2$, which means that the osteosynthesis "settles". If we apply the same load as before ($P_3=P_1$) no further irreversible shortening occurs. The osteosynthesis has been stabilized by higher load P_2 for any smaller loads, e.g. P_3.

DISCUSSION

The implant and/or the intact or reconstructed cortex have to stabilize the fracture and carry loads without any essential deformation until osseous healing has taken place. If medial support exists the load is chiefly carried by the bone, the main task of the implant being the fixation of the ends of the fractured bone in an exact position. If, however, there is no load-carrying medial support diverse behaviour of both varieties of implants is evident.

As far as the angled plate is concerned the axis of rotation of the motion shifts from the medullary space to the section between the blade and plate so that not only the lever arm is considerably lengthened but due to the high local tensile stresses a considerable plastic (=irreversible) deformation also develops. The cyclic loading of the metal in this highly stressed area is the reason for fatigue fracture of the implant which sometimes occurs.

Because of the intramedullary position of the flexible condylar nails the axis of rotation cannot shift as far outward as in the case of the angled plate even if the medial support is lacking. The result is a better biomechanical relation between the length of the implant and the length of the lever arm. By putting the fracture in a valgus position the load-carrying lever arm can be further shortened so that this relation is improved. Localized strain is not expected with this kind of implant since the deformation under load is distributed over a considerable length (Figure 2b). Therefore fatigue fracture cannot appear.

As the loading of an extremity in the postoperative phase is of the order of 80 kp, the angled plate and flexible condylar nails are both stable osteosyntheses, provided that there is medial support. If medial support is lacking, stable osteosynthesis can be ensured by putting the fracture in a valgus position by means of flexible condylar nails even if osseous contact in the area of the medial cortex is not recreated. Consequently the intentional neglect of exact osseous reconstruction in favour of technically simple surgery which can be quickly performed is justified in the treatment of pertrochanteric fractures.

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