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A PHOTOELASTIC STUDY OF THE HIP NAIL-PLATE IN UNSTABLE TROCHANTERIC FRACTURES

A Biomechanical Study of Unstable Trochanteric Fractures II

J. STEEN JENSEN

Biomechanics Laboratory, Department of Orthopaedic Surgery T-2,
Gentofte Hospital, Hellerup, Denmark

The photoelastic technique was applied to acrylic models of unstable trochanteric fractures. Model osteosynthesis was performed on nail-plates with different angles. An increase of the angle between the nail and plate was shown to reduce the shear force between those two components considerably. From mechanical considerations it is recommended that a steep placement of the nail-plate is advantageous in osteosynthesis of unstable trochanteric fractures without medial support.

Key words: biomechanics; femoral neck; trochanteric fractures; osteosynthesis

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From clinical reports on nail-plate osteosynthesis of unstable trochanteric fractures it is known that mechanical failure of implants occurs in about 15–25 per cent of cases (Cram 1955, Dimon & Hughston 1967, Foster 1958, Jensen & Michaelsen 1975).

Experiments on the mechanical properties of hip nail-plates have been carried out, but have mostly considered differences in design and materials (Harvey et al. 1959, Foster 1958, Kaufer et al. 1974, Martz 1956). It has been mentioned that the connection between the nail and the plate represents a weak point in the construction (Foster 1958, Grover 1966, Martz 1956). In nailing of femoral neck fractures it was demonstrated through photoelastic studies (Haboush 1952, 1953) that a steep placement of the nail with support on the calcar femorale significantly reduced the stress in the nail.

The aim of this study has been to demonstrate changes in the stress patterns in the hip nail-plate according to alterations of the nail-plate angle. The photoelastic technique was used although it only considers the stress patterns in the two-dimensional frontal plane.

MATERIALS AND METHODS

The photoelastic technique and its application in studies of the proximal femur has been thoroughly described in a previous report (Jensen 1978).

Based on measurements on hip nail-plates of the Jewett-type (Howmedica Inc., catalogue no. 6403-1) two-dimensional models were manufactured from 10 mm thick polyester plates (Araldite-B®) with nail-plate angles of 125°, 135°, 140°, 150° and 160°. Models of the proximal femur with a standardized trochanteric fracture without medial support were also manufactured from 10 mm Araldite-B®. Models with femoral neck angles of 130° as well as 140° were made, and model-osteosyntheses were performed with the acrylic nails. The experimental arrangement was similar to

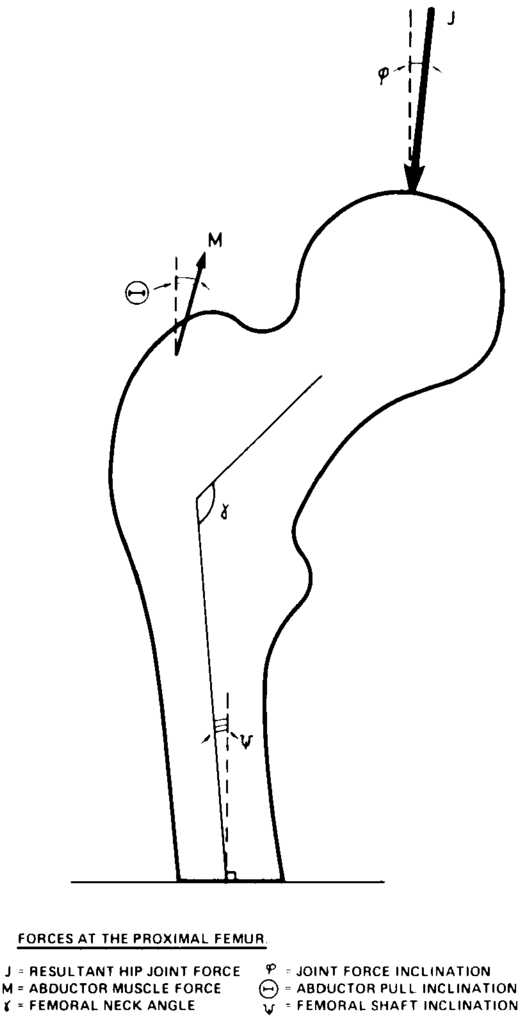

Figure 1. Forces at the proximal femur.

the description given in the previous paper (Jensen 1978). This included loading of the model in a polariscope with simultaneous application of abductor muscle force. The femoral shaft inclination (ψ) was 5°, the joint force inclination (φ) 6°, the abductor pull direction (Θ) 15° and the magnitude of the abductor pull (M) was 55 per cent of the joint force (J) (Figure 1). Lines of constant shear stress in the nail-plate, the isochromates, were numbered from the centrally placed neutral axis in the distal 3 cm of the nail and the proximal 3 cm of the plate before the connection to give the order of the isochromates.

The models of the nail-plates were loaded in the vertical position and at 11° inclination to the vertical to clarify the influence of the femoral shaft inclination ($\psi = 5°$) and the inclination of the hip joint force ($\varphi = 6°$).

The osteosynthesis models of the unstable trochanteric fracture were loaded at 11° inclination, with the hip joint force amounting to 15.0 Newton. In order to clarify the influence of the abductor muscle force this was applied with 15° inclination and amounted to 55 per cent of the hip joint force (= 8.25 Newton).

Table 1. Order of isochromates according to nail-plate angle

Nail-plate angle	Order in nail	Order in plate
125°	5.0	6.5
135°	4.5	5.5
140°	4.0	5.0
150°	3.5	4.5
160°	3.0	3.5

The values stated are average values.
The order in the nail is counted 3 cm proximal to the connection between nail and plate and the order in the plate 3 cm distal to the connection.

RESULTS

Twenty experiments were performed with the nail-plate models and 47 experiments with the osteosynthesis models of the unstable trochanteric fracture without medial support.

Table 1 demonstrates that an increase of the angle between the nail and the plate significantly reduced the order of isochromates ($P < 0.0005$, Kruskall-Wallis test).

The maximum shear force (τ_{max}) in the model of the nail can be expressed by the equation (Föppl & Mönch 1972):

$$(1)\ \tau_{max} = \frac{S}{0.2 \times d} \times \delta$$

(S = photoelastic constant, which for Araldite-B® = 1.0 N/mm², d = thickness of model = 10 mm, δ = order of the isochromates). For the current experiments the equation will thus be:

$$(2)\ \tau_{max} = 0.5 \times \delta\ \text{N/mm}^2$$

The order of isochromates in the distal part of the nail of a 125° nail-plate (Figure 2) was

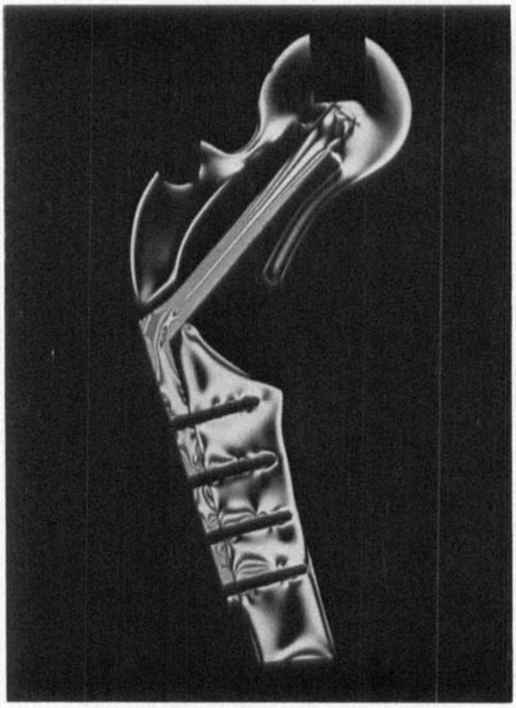

Figure 2. Stress patterns in a 125° nail-plate. The thin interrupted centerline is the neutral axis (= zero-isochromate). The isochromates are numbered from the neutral axis. In the distal part of the nail near to the connection with the plate five isochromates can be counted.

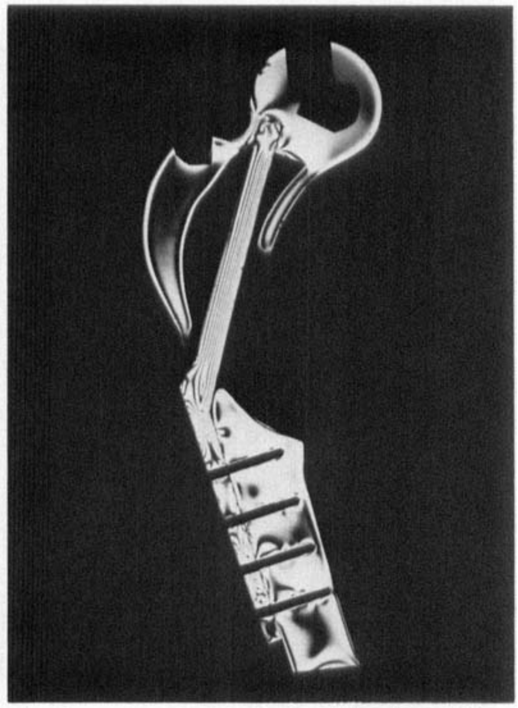

Figure 3. Stress patterns in a 150° nail-plate. In the distal part of the nail near the connection with the plate 3.5 isochromates can be counted on each side of the centrally placed neutral axis.

found to be 5.0 (Table 1). The maximum shear stress is thus calculated as:

$$\tau_{\max 125^\circ} = 0.5 \times 5.0 = 2.5 \text{ N/mm}^2$$

For a 150° nail-plate (Figure 3) the order of isochromates was 3.5 (Table 1) and the maximum shear stress is calculated as:

$$\tau_{\max 150^\circ} = 0.5 \times 3.5 = 1.75 \text{ N/mm}^2$$

The reduction in shear stress is thus about 30 per cent by using the 150° nail-plate as compared with the 125° nail-plate. As seen from Table 1 the order of isochromates and thereby the maximum shear stress is even larger in the proximal part of the plate.

By applying a nail-plate with a steeper angle the reduction of the shear forces will also be considerably larger in this area. Experiments on the osteosynthesis models also demonstrated that the abductor muscle force increased the shear forces. The order of isochromates was 0.5–1.0 higher when the abductor pull was applied to the model compared to the situation where the hip joint force was acting separately.

The experiments on the nail-plate models demonstrated that loading the model at an inclination of 11° to the vertical, corresponding to a femoral shaft inclination of 5° and a joint force inclination of 6°, reduced the order of isochromates by 0.5–1.5 in the distal part of the nail and by 1.0–2.0 in the proximal part of the plate as compared with the arrangement with the plate positioned vertically.

DISCUSSION

From biomechanical experiments on medial femoral neck fractures (Haboush 1952, 1953, Harvey et al. 1959, Spotoft 1949) it is known that a steeper placement of the nail reduces the load on the nail and thereby increases the mechanical strength of the osteosynthesis. Frankel (1963), however, pointed out the importance of considering also the trabecular structure and the mechanical properties of the bone.

In the unstable trochanteric fracture without medial support the nail-plate alone transmits the entire load from the femoral head to the femoral shaft. Sarmiento (1963) recommended a steep placement of the nail in trochanteric fractures to reduce the mechanical load on the implant. Some authors (Foster 1958, Grover 1966, Martz 1956) mentioned that the connection between the nail and the plate was the weak point in the construction and thus the most susceptible to mechanical failure.

The photoelastic technique used in this series has its obvious limitations (Jensen 1978). The stress patterns are for instance only considered in the frontal plane, and deformation of the model is assumed not to alter the stress patterns. The model is considered free from sagittal forces.

In the rather simple mathematical calculations given in this paper the maximum shear stress in the distal part of the nail of a 125° nail-plate was found to be 2.5 N/mm^2 when the model was loaded with 15.0 N. In comparison, the maximum shear force in the nail of a 150° nail-plate was calculated as 1.75 N/mm^2. From Paul's studies (1967) it is known that the human hip joint is exposed to forces of about six times the body weight in normal level walking.

A rather simple calculation can be made from the experimental values to estimate the *in vivo* shear forces on the Jewett-nail for each step a woman of 60 kg ($\approx$589 N) takes during walking. The maximum shear stress in a 125° nail-plate would thus be calculated to be: $2.5/15.0 \times 589 \times 6 = 589$ N/mm^2. In a similar situation applying a 150° nail-plate the maximum shear stress amounts to: $1.75/15.0 \times 589 \times 6 = 412$ N/mm^2, which is only 70 per cent of the stress on the 125° nail-plate. As the hip is exposed to cyclic loading during walking the implant has to absorb a considerable amount of energy during the time of fracture union. The risk of implant failure due to metal fatigue increases with increased shear force.

In this series only the stress patterns in the implant have been considered. The mechanical behaviour of the surrounding bone with its osteoporosis and reduced mechanical strength has not been taken into account and neither has the geometry of the bone-nail interface. Further laboratory investigations will therefore be undertaken on cadaveric bone to clarify the mechanical behaviour of the unstable trochanteric fracture without medial support.

From this series of experiments it can be concluded that in osteosynthesis of unstable trochanteric fractures a steep placement of the nail-plate is to be recommended from purely mechanical considerations.

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Correspondence to: J. Steen Jensen, M.D., Tornehøj 23, DK-3520 Farum, Denmark.