A new nail-plate for treatment of fracture of the neck of the femur

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Abstract

Operative treatment of fractures of the neck and trochanter of the femur does not always produce a satisfactory result. This is usually due to biomechanical problems with the available internal fixation methods. We studied the anatomy of the neck of the femur by roentgenograms and sectional specimens from 70 cadavers. In addition, various nail-plates were subjected to buckling tests and, by simultaneously attaching a strain-gauge, stress distribution was calculated. The results of these preliminary studies were then used to design a new nail-plate better than those available at present. Testing of this new nail-plate confirmed that it had a strength equal to that of the Holt nail-plate (the strongest of the available nail-plates).

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A NEW NAIL-PLATE FOR TREATMENT OF FRACTURE OF THE NECK OF THE FEMUR

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Abstract. Operative treatment of fractures of the neck and trochanter of the femur does not always produce a satisfactory result. This is usually due to biomechanical problems with the available internal fixation methods. We studied the anatomy of the neck of the femur by roentgenograms and sectional specimens from 70 cadavers. In addition, various nail-plates were subjected to buckling tests and, by simultaneously attaching a strain-gauge, stress distribution was calculated. The results of these preliminary studies were then used to design a new nail-plate better than those available at present. Testing of this new nail-plate confirmed that it had a strength equal to that of the Holt nail-plate (the strongest of the available nail-plates).

Treatment for fracture of the neck of the femur has developed greatly since the appearance of the three flanged nail (Smith-Petersen, 1931), which was later welded to a one-piece nail-plate (Jewett, 1941) (1). Since then, various improvements have been made and the resultant nail-plate is now being widely used.

Since 1968, we have been using Jewett nail-plates made of COP (an excellent alloy developed in Japan) for the treatment of fractures of the neck of the femur and of the distal end of the femur (2). Using this nail-plate, results for the treatment of fractures of the neck of the femur have improved greatly. However, in the rare case, breakage of the three flanged nail has occurred. Therefore, the Jewett nail has been re-examined from a biomechanical viewpoint and the data so obtained used to improve the nail-plate.

Anatomical study of the neck of the femur.

Femurs were studied in 70 Japanese cadavers. Roentgenographic pictures were taken from two directions, i.e. from antero-posterior and lateral directions of the neck of the femur. The diameter of the bone marrow cavity at the isthmus (the narrowest part of the femoral neck) was then calculated from these two views. This measured between 21.5 mm and 35.7 mm, with a mean of $28.9 \pm 5.5$ mm in the antero-posterior view, and between 19.5 mm and 32.6 mm, with a mean of $24.6 \pm 5.5$ mm, in the lateral view.
Serial sections were performed on 22 of these femurs as follows: a line was drawn at 140° to the lateral aspect of the femoral shaft to pass through the head of the femur. Sections perpendicular to this line were then made at 5 mm intervals, beginning at the subcapital line and proceeding outwards as far as the greater trochanter. These sections were studied by roentgenography (Fig. 1).

Fig. 1. Cross-sections of femoral necks. These show roughly a “reversed isosceles triangle” shape at the isthmus.

A three-armed ruler (the angle between arms all being 120°) was then pasted on the roentgenogram specimen at two places, one at the isthmus, and one at the base of the femoral neck. The distance from the center of the bone cortex was then measured (Fig. 2).

The cut surface of the femoral neck formed roughly a “reversed triangle”. The upper flange at the isthmus measured between 10.0 mm and 15.0 mm in length, the mean being 12.8 ± 2.1 mm. The lower flange was between 12.5 mm
and 18.0 mm, with a mean of $15.1 \pm 2.5$ mm. At the base of the femoral neck, the upper flange measured between 11.0 mm and 15.0 mm in length, the mean being $12.9 \pm 2.5$ mm.

![Fig. 2. Measurement of the bone marrow cavity on cross-sectional specimens. X = two upper flanges; Y = lower flange](image)

The minimum diameter (19.5 to 21.5 mm) of the above-mentioned isthmus was quite large compared with the diameters (11 to 13 mm) of conventional three flanged nails. Similarly, the minimum diameters (10.0 to 13.0 mm) of the upper and lower flanges of the isthmus were quite large in comparison with the flanges of conventional nails.

### Buckling tests of nail-plates.

The 9 kinds of nail-plates tested are shown in Table 1. The nail length was 90 mm. In buckling tests with a perpendicular load, the point of action of the load tends to shift to the tip of the nail when the nail-plate buckles. The load in

<table>
<thead>
<tr>
<th>Nail-Plates</th>
<th>Shape of Nail</th>
<th>Metal</th>
<th>Angle</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. McLaughlin</td>
<td>Smith-Petersen type (tri-flanged nail)</td>
<td>SMo</td>
<td>130°</td>
<td>11.0 mm</td>
</tr>
<tr>
<td>2. Jewett (Zimmer)</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>13.0 mm</td>
</tr>
<tr>
<td>3. Jewett</td>
<td>&quot;</td>
<td>Vitallium</td>
<td>&quot;</td>
<td>12.5 mm</td>
</tr>
<tr>
<td>4. Jewett</td>
<td>&quot;</td>
<td>COP</td>
<td>&quot;</td>
<td>13.0 mm</td>
</tr>
<tr>
<td>5. Jewett</td>
<td>&quot;</td>
<td>&quot;</td>
<td>150°</td>
<td>&quot;</td>
</tr>
<tr>
<td>6. AO</td>
<td>U-shape</td>
<td>SMo</td>
<td>130°</td>
<td>/</td>
</tr>
<tr>
<td>7. Pugh</td>
<td>rod</td>
<td>&quot;</td>
<td>&quot;</td>
<td>12.5 mm</td>
</tr>
<tr>
<td>8. Holt</td>
<td>rod</td>
<td>Vitallium</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>9. Trial</td>
<td>3 flanges + rod</td>
<td>COP</td>
<td>140°</td>
<td>16, 18 mm</td>
</tr>
</tbody>
</table>
this test, therefore, was designed so that the point of action was always stable. This was achieved by an arrangement which allowed the load to slide with the buckling of the nail-plate so that the point of action transmitted from the autograph was always at the tip of the nail. The direction of the load was always perpendicular. (Fig. 3).

Fig. 3. Buckling test. Part of the load slides with buckling of the nail-plate.

The distance between the upper end and the angle of the nail-plate was fixed at 20 mm. The measurement was taken with an autograph (IS 5,000 type SHIMAZU), and load-deflection diagrams recorded.

Comparison of the load, elastic limit and maximum load produced by total deflection and residual deflection with fixed loads (20, 40, 60, 80, 100 kg) showed that the Holt nail-plate was strongest and the McLaughlin nail-plate was weakest. The Vitallium nail-plate was unexpectedly weak (Fig. 4).
Fig. 4. Load-deflection diagram of the nail-plates. The Holt nail-plate is strongest followed by the trial nail-plate. The McLaughlin nail-plate is weakest.

Vitallium-H = Holt nail-plate (Vitallium)
COP = Trial nail-plate
SMo-P = Pugh sliding nail
COP-J. 150° = Jewett nail-plate (150°, COP)
COP-J. 130° = Jewett nail-plate (130°, COP)
SMo-J-Z 130° = Jewett nail-plate (Zimmer)
Vitallium-J. 130° = Jewett nail-plate (Vitallium)
AO = AO angled plate
SMo-M = McLaughlin nail-plate, 130°

Fig. 5. Specifications of the trial nail-plate. The nail portion consists of a three-flanged part and a rod part. The cross-section is an oval shape.
STRESS DISTRIBUTION ON NAIL-PLATES

With three kinds of nail-plates, the 130° COP-nail-plate, the AOI angled plate, and the Holt nail-plate, strain gauges were pasted at 14 to 17 points. As for the previous buckling tests, perpendicular loads were used and changes in electrical resistance at the points pasted with strain gauges were measured by a strain meter. The maximum value occurred at the junction of the tri-flanged portion and the rod in the Jewett nail-plate, but at the angle in both the AOI-angled plate and the Holt nail-plate. The AOI-angled plate showed greater values at all portions than the other two nail-plates.

DESIGN AND STRENGTH OF THE TRIAL NAIL-PLATE

A biomechanically rational nail-plate was designed on the basis of the above findings. The shape of the nail to be inserted into the trochanter and the neck of the femur was designed, as a rule, to conform to the shape of the neck of the femur. Its cross-section is shaped like a reversed isosceles triangle, resembling a hen's egg. The longest diameter is 18 mm and the shortest diameter, 16 mm.

The part for insertion into the head of the femur was designed as a tri-flanged nail in order to improve resistance to rotational stresses. Each of the upper two flanges measures 8 mm. The lower flange is 11 mm (Fig. 5). The rod portion measures 45 mm from its junction with the plate. The remainder constitutes a tri-flanged nail.

Fig. 6. The trial nail-plate and two other nail-plates. a. Jewett nail-plate (130° COP); b. trial nail-plate; c. AO angled plate.
With this design, the fracture line in intertrochanteric fractures of the femur passes through the rod portion. The plate-nail angle is fixed at 140° and the plate portion has buttress type screws like the AOI plates shown in Figs. 5 and 6.

A trial nail-plate was made from COP alloy to these specifications. Its strength as measured by the buckling test was almost as great as that of the Holt nail-plate which is a rod in nail type (Fig. 4). Similarly, since the junction of the tri-flanged portion to the rod had been moved to the 45mm tip, the weakest point, as shown by the stress distribution, had shifted to the angle of the nail-plate (Figs. 6 and 7).

**DISCUSSION**

In Japan, internal fixation for fractures of the neck of the femur in elderly patients seems to be based on the use of one-piece nail-plates such as the Jewett nail-plate.

There are many kinds of nail-plates available today, each the product of...
some original idea and design, but very few have undergone sufficient biomechani-
cal testing. Consequently, there are occasional cases of bending or failure of
the nail and screw (3, 4, 5).

The essential conditions for an ideal nail-plate are as follows: (a) The
strength of the nail-plate itself should be high. (b) The nail portion must conform
to the anatomical architecture of the femoral neck. (c) Internal fixation should be
achieved by intramedullary nailing with a three-flanged nail even with fractures
of the neck of the femur. (d) The nail portion should be rigidly fixed against
rotational stresses. (e) The nail portion should not interfere with circulation in
the marrow cavity of the neck of the femur.

Various nail-plates were studied with these points in mind. Firstly, the
relation of the shape of the femoral neck to the nail was examined. The cross-
section of the isthmus of the femoral neck is an elliptical shape close to a reversed
isosceles triangle. Any three flanged nail to be used in this area should not be the
regular round shape but should be an asymmetric three-flanged nail with a long
lower flange. Most of the three-flanged nails available are 13 mm in diameter.
The concept of internal fixation to the neck of the femur by a three-flanged nail
falls within the range of intramedullary nailing, so any nail used should have
as large a diameter as possible. A diameter less than 13 mm should be considered
too small.

Our nail-plate has a shape eminently suitable to the isthmus of the femoral
neck. The strengths of various nail-plates have been reported by Martz (6),
Foster (7), Frankel (8) and Holt (9), but their methods present problems, espe-
cially during the loading tests. Since the load as they apply it does not necessarily
remain at the apex of the nail-plate, their methods are of questionable accuracy.

Even during the sliding pattern of the load portion, our nail-plate buckles so
that the part that receives the load is fixed and that the direction of loading
remains perpendicular.

The load-deflection diagram obtained by autograph was used to compare
precisely the relationship of the load (elastic limit) with the deflection occurring
immediately before the onset of permanent deflection.

Strength as measured by buckling tests showed that the Holt nail-plate was
strongest, followed by our trial nail-plate. The Holt nail-plate cross-section is
round throughout and this difference in shape accounts for the extra strength.

The Jewett nail-plate which is made of Vitallium was unexpectedly weak,
about one half the strength of the COP-nail-plate. The fact that Vitallium is not
as superior in strength as is generally believed has been pointed out previously by
Lindahl (10) and Sunami (2). The stress distribution with a fixed load was
studied with strain gauges. With the Jewett nail-plate, the maximum stress
occurred at the junction of the three-flanged portion and the rod portion. This
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means that the three-flanged nail-plate designed to yield a stronger resistance to rotational stresses has a morphological deficit at the junction of the three-flanged portion and the rod portion, a fact which corresponds to the bending or breakage observed in some clinical cases.

From the above findings, we consider that the nail-plate shown in Fig. 4 has an anatomical architecture that greatly reinforces its strength and that offers a greater resistance to rotational stresses, as well as conforming better with the shape of the neck of the femur.

SUMMARY

A nail-plate was designed from biomechanical and biological considerations and its strength tested. It was shown to have a strength practically the same as the Holt nail-plate made of Vitallium, which is the strongest nail-plate available at present. This trial nail-plate fits the anatomical shape of the neck of the femur well and is superior to the Holt nail-plate in its resistance to rotational stresses.

REFERENCES