BONE WEAKNESS AFTER THE REMOVAL OF PLATES AND SCREWS

CORTICAL ATROPHY OR SCREW HOLES?

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Bone weakness leading to refracture is a recognised complication of the removal of rigid fixation plates. We have used partially demineralised rabbit tibiae to simulate atrophic changes and to determine whether weakness is due to atrophy or to residual screw holes.

Partial demineralisation and a screw hole each reduced maximum bending moment. However, energy absorbing capacity was little affected by demineralisation, but was reduced to 50% by a single drill hole. Residual screw holes are a considerably more important cause of bone weakness after plate removal than is cortical atrophy.

It is well established that after removal of an internal fixation plate the residual bone is weaker than normal (Uthoff and Dubuc 1971; Burstein et al 1972; Akeson et al 1976; Paavolainen et al 1978b; Slätis et al 1978; Strömberg and Dalen 1978; Terjesen and Benum 1983). A reported incidence of refracture of up to 20% indicates that this problem has clinical relevance (Hidaka and Gustilo 1984; DeLuca, Ruwe and Lindsey 1987).

Loss of strength after plate removal has been attributed to residual screw holes, and also to the adverse effect of rigid plates on bone structure, caused by 'stress protection' leading to atrophy (Tonino et al 1976; Moyer et al 1978). More recently it has been suggested that atrophy may be due to vascular disturbance rather than mechanical effects (Gunst, Suter and Rahn 1979; Gunst 1980; Jacobs, Rahn and Perren 1981; Perren et al 1988), and finite element analysis has thrown doubt on the advantages of reducing the stiffness of plates (Cordey and Perren 1984). Nevertheless the 'stress protection'

concept has encouraged the development of less rigid plates (Tayton et al 1982).

We have tried to determine the relative contributions of cortical atrophy and residual screw holes to reduced bone strength after plate removal. We used partially demineralised bones as models of cortical atrophy (Monro, Purrier and Shearer 1987), and compared the effect of demineralisation on mechanical properties with that of drill holes in normally mineralised bone.

MATERIALS AND METHODS

Paired tibiae obtained from New Zealand white rabbits were used, one under test and the contralateral bone as control. The bones were stripped of all soft tissue and the fibula was excised proximal to the tibiofibular synostosis. Bone mineral content was measured by single photon absorptiometry using a Nuclear Data model ND 1100A bone mineral analyser (Nuclear Data Medical Products, Michigan, USA).

Cortical atrophy model. Fourteen test bones were each immersed in 300 ml of 1% Gooding and Stewart's demineralising fluid for predetermined periods to achieve a range of bone demineralisation. The contralateral control bones and three control pairs were immersed in buffered formalin for similar periods. All bones were then washed and stored in normal saline before testing. Bone mineral content was determined for each test bone before and after demineralisation.

In animal studies, rigid plate fixation has been reported to reduce mineral content by as much as 26% (Paavolainen et al 1978a; Terjesen and Benum 1983).

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We therefore concentrated on mineralisation levels of between 70% and normal.

Residual screw hole model. A single hole was drilled through each of nine test bones perpendicular to the mid-point of the subcutaneous border of the tibia. The triangular cross-section of the tibia allowed us to place each specimen in a loading rig so that the axis of the drill hole was always at 45° to the axis of the applied load (Fig. 1). Three types of hole were considered: 1.5 mm, 1.5 mm screw tapped to 2.0 mm, and 2.0 mm.

Fig. 1

Previous studies have suggested that a solitary hole reduces bone strength by approximately 50% irrespective of the diameter of the hole, provided it does not exceed 30% of the diameter of the bone. In our study no hole exceeded 30% of the mid-section diameter of the bone: the model was therefore a fair representation of the defects which remain in human forearm bones after the removal of 'small fragment' screws.

Table I. Mechanical properties related to bone mineral content (results expressed as percentages of control bone values)

Bone mineral content	Maximum bending moment	Elastic stiffness	Energy absorbed
29	10	0.0009	—
60	59	36	104
70	78	57	121
74	78	54	105
78	78	61	119
81	66	40	105
81	80	89	80
82	66	67	66
83	73	71	78
85	84	60	114
87	83	76	93
91	81	84	73
92	83	67	115
94	90	83	102
98c	104	103	108
101c	101	95	104
98c	101	98	100

c = control pair

Cortical atrophy plus screw hole. The combined effects of cortical atrophy and a residual screw hole were tested by drilling a 1.5 mm hole in six test bones prepared to varying degrees of demineralisation.

Mechanical testing. Three-point bending was chosen to achieve maximum bending moment in the section of bone incorporating the hole; a frame was designed to accommodate the rabbit tibia in an Instron test machine. Deformation at the centre support, at the mid-point of each bone, was increased at the rate of 0.5 cm per minute. The load applied and the deformation at this mid-point, for each test and control bone, were recorded to failure. The yield point was taken as the end of the initial linear part of the force/deformation curve. The maximum applied load and the slope of the curve were recorded to allow calculation of the maximum bending moment, the elastic stiffness (force per unit deformation), and the energy absorbed prior to failure. Elastic stiffness was derived from the slope of the curve, and the energy absorbed from the area under the curve.

Statistical analysis. Correlation (r) was calculated using Pearson's product moment coefficient, and probability (p) was calculated for values of r .

RESULTS

Mechanical testing of the three pairs of control bones confirmed the previously reported high degree of symmetry between paired rabbit bones. This justified the use of the contralateral bone as a control (Paavolainen et al 1978a,b; Laftman, Sigurdsson and Strömberg 1980; Terjesen and Benum 1983).

The results derived from the test bones are expressed

Fig. 2

The influence of bone mineral content (BMC) and of various drill holes (D) on maximum bending moment (MBM) expressed as percentages of control values. Mineral content O vs MBM: $r = 0.93$, $p < 0.001$. For types of drill hole see text.

as percentages of the control values and are set out as follows:

- partial demineralisation, Table I and Figures 2 and 3;
- drill holes in normal bone, Table II and Figures 2 and 3;
- partial demineralisation plus drill holes, Table III.

Table II. Mechanical properties related to the presence of a drill hole, given as *percentages* of control values (mean and standard deviation of three pairs in each group)

Hole (mm)	Maximum bending moment	Elastic stiffness	Energy absorbed
1.5	70 (7.8)	93 (6.0)	53 (11.1)
1.5 tapped	64 (4.0)	88 (16.8)	48 (7.2)
2.0	66 (3.2)	97 (18.8)	49 (9.9)

Table III. Mechanical properties related to mineral content in bones with a 1.5 mm drill hole given as *percentages* of control value

Bone mineral content	Maximum bending moment	Elastic stiffness	Energy absorbed
69	49	41	55
76	51	64	43
79	56	56	58
81	69	63	68
96	61	86	42
99	63	103	37
100	76	99	59
100	73	93	59
100	60	86	40

Fig. 3

The influence of bone mineral content (BMC) and of various drill holes (D) on energy absorbing capacity (EA) expressed as percentage of control values. Mineral content ○ vs EA: $r = -0.25$, $p < 0.5$.

We found a strong positive correlation between mineral content and both maximum bending moment and elastic stiffness. Because energy absorbing capacity is a function of both the maximum bending moment and the deformation prior to failure, there was no clear relationship between mineral content and energy absorbing capacity. Reduction in mineral content to between 75% and 85% of normal reduced maximum bending moment to a mean of 75% of normal (66% to 84%) while energy absorbing capacity was reduced only to a mean of 94% of normal (66% to 119%).

The effect of a drill hole was to reduce maximum bending moment while exerting only a minimal effect on elastic stiffness. Consequently, a drill hole substantially reduced energy absorbing capacity. A 1.5 mm drill hole reduced maximum bending moment to 70% of normal (60% to 76%) and energy absorbing capacity to 53% of normal (40% to 59%). As was anticipated from the results of previous studies the dimensions of the hole were not related to the mechanical consequences (Bechtol, Ferguson and Laing 1959).

In the presence of a hole, partial demineralisation further reduced the maximum bending moment. However, the reduced stiffness of the bone resulted in an energy absorbing capacity similar to that seen in normally mineralised bone with a drill hole. Therefore the effects of demineralisation and of a drill hole can be accounted for simply by combining the two effects.

It is evident that the results for energy absorbing capacity showed considerable scatter. It is therefore important to note that in no demineralised specimen did energy absorbing capacity fall below 60% of normal, while in no normally mineralised specimen with a drill hole did energy absorbing capacity exceed 60% of normal (Fig. 3).

DISCUSSION

Population studies of specimens from different individuals have demonstrated a positive correlation between mineral content and static strength (Currey 1969; Bartley et al 1966). However, the effect of variation in mineral content within an individual bone has not been established. As was expected, we found a positive correlation between mineral content and maximum bending moment in individual bones subjected to partial demineralisation. A similar correlation between mineral content and elastic stiffness means that there was no clear relationship between mineral content and energy absorbed at the fracture.

While maximum bending moment reflects static strength, energy absorbing capacity takes into account both maximum bending moment and the degree of deformation at failure. Given that static strength is sufficient to maintain posture, it would seem that energy absorbing capacity is far more relevant to resistance to fracture in the dynamic activities of everyday life.

In our study, reduction in bone mineral content to between 75% and 85% of normal resulted in a reduction in maximum bending moment to an average of 75% of normal; the average energy absorbing capacity was reduced only minimally to 94% of normal. In contrast a single drill hole reduced energy absorbing capacity by approximately half. The effect on maximum bending moment was less pronounced but in all cases it was less than 76% of normal. If the separate effects of partial demineralisation and of a drill hole are compared with the effects of both combined, it is evident that strength reduction resulted predominantly from the hole.

It has been postulated that bone remodelling maintains a ratio between organic and inorganic material to optimise energy absorbing capacity (Currey 1976). Rigidly plated bone would therefore be expected to lose a greater proportion of its inorganic material. Thus the demineralisation model used in this study may more closely reflect cortical atrophy in the clinical situation than at first appears.

Bone is known to remodel in the presence of a screw but it has been shown that once the screw is removed bone strength reverts to that seen immediately after the

insertion of the screw (Burstein et al 1972). This validates our use of fresh drill holes as a model of the clinical situation. We have considered only the relative effects of atrophic changes under a plate and residual screw holes; in the clinical situation the transition zone between plated and unplated bone creates a further potential stress raiser.

Studies of the effects of rigid plates in animals have highlighted cortical atrophy as an important disadvantage, and have helped to stimulate the search for less rigid plates. These plates may have some advantages in terms of allowing fracture defects to fill with callus (Tayton et al 1982), but screw fixation is still required, so there are very similar residual defects after plate removal.

Our results suggest that strength reduction after the removal of a plate is related more to the presence of residual screw holes than to cortical atrophy. The value of reducing the rigidity of plates to diminish 'stress protection' must be questioned.

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