Implant holding power of the femoral head

A cadaver study of fracture screws

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The holding power against axial pull-out forces of eight different screws implanted in the femoral heads of cadavers was tested. The Olmed screw had the greatest resistance to pull-out forces followed by the recently designed Ullevaal screw with long threads, and the von Bahr screw.

There were substantial differences in the holding power in the four sectors of the femoral head. The holding power was strongly correlated with the logarithm of the moment of inertia of the screw threads, which is a function of the area and number of the threads (r = 0.94, P= 0.0002).

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The holding power against axial pull-out forces of a screw implanted in bone is one of the important characteristics of the implant (Swiontkowski et al. 1987). The holding power is a function of the characteristics and properties of both the bone and the implant. The clinical importance of the pull-out strength when a screw is used for fixation of femoral neck fractures is, however, not known.

The purpose of this study was to test a new screw construction with equal shank and thread diameters against other constructions. We present the results of pull-out tests for four different prototypes of the new Ullevaal screw and for four types of commercially available screws that are widely used for fixation of femoral neck fractures.

Materials and methods

Eight pairs of femurs were collected at autopsy from 9 men, median age 74 (42–81) years, and 7 women, median age 84 (56–93) years, with none of them being known to have had diseases affecting bone. Eight different screws designed for fixation of fractures of the femoral neck were tested in each pair of femora (Figure 1, Table 1). Eight screws of each of the eight types were tested in four positions of the femoral head: viz., superior, inferior, posterior, and anterior. The selection of screw positions allowed each screw to be inserted twice in each position in different femora.

The screws were inserted as recommended by the manufacturers. The prototype screws were inserted into a drill track 7 mm in diameter through the femoral neck. All the screws were driven into the subchondral area of the femoral head (Rehnberg et al. 1988). An Instron TMM 5-ton Universal Testing Machine, which was used for the static pull-out tests, exerted a constant pull of 5 mm/min. The maximal load needed to retract the screw was recorded as maximal holding power.

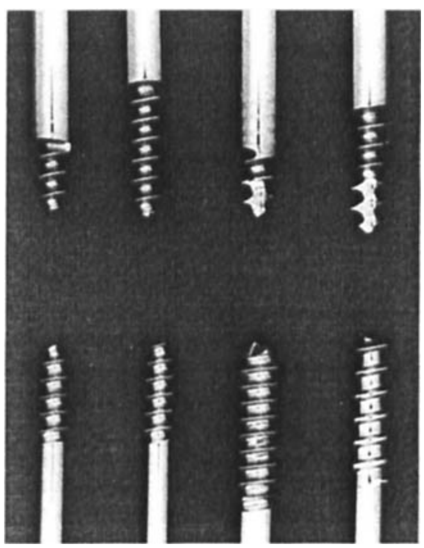


Figure 1. The threads of the screws used in the test.
Upper row, prototypes of the Ullevaal screw. From left: Nonself-tapping with short threads, nonself-tapping with long threads, self-tapping with short threads, self-tapping with long threads. Lower row, from left: Mecron screw, AO cancellous screw, Olmed screw, von Bahr screw.

Table 1. Characteristics and maximal holding power of each type of screw

Screw	Shank diameter (mm)	Thread diameter (mm)	No. of threads	Core of the thread (mm)	Maximal load (N)	*SD*
1	7.0	7.0	3	2.5	780	*266*
2	7.0	7.0	3	2.5	1,163	*457*
3	7.0	7.0	6	2.5	1,428	*899*
4	7.0	7.0	6	2.5	1,837	*981*
5	4.5	6.5	5	3.0	1,187	*562*
6	5.5	7.1	6	4.2	1,668	*641*
7	6.0	8.0	9	4.0	2,074	*941*
8	5.0	6.5	5	3.5	1,177	*301*

Screw. 1 Prototype, short thread, self-tapping.
2 Prototype, short thread, nonself-tapping.
3 Prototype, long thread, self-tapping.
4 Prototype, long thread, nonself-tapping.
5 AO 6.5-mm cancellous screw;
6 von Bahr screw; core is cone-shaped, mean 4.2 mm.
7 Olmed screw.
8 Mecron screw.
The area of the first three threads of the self-tapping Ullevaal screw is reduced because of the self-tapping design.

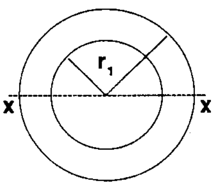
Table 2. Statistical grouping of the implants (least significant difference pairwise comparisons of means). $P < 0.05$

Screw	Mean	Homogeneous groups 1	2	3
7	2,074 N	*		
4	1,837 N	*	*	
6	1,668 N	*	*	
3	1,428 N	*	*	*
5	1,187 N		*	*
8	1,177 N		*	*
2	1,163 N		*	*
1	780 N			*

Screw. See Table 1.

Table 3. Holding power (N *SD*) and statistical grouping of the different sectors of the femoral head ($P < 0.05$)

Position	Holding power		Statistical grouping 1	2	3
1 (superior)	1,774	*846*	*		
4 (anterior)	1,654	*752*	*	*	
3 (posterior)	1,263	*619*		*	*
2 (inferior)	996	*538*			*



$$MI_{XX} = \pi \frac{(r_0^4 - r_1^4)}{4}$$

Figure 2. Calculation of moment of inertia (MI) for a structure similar to one screw thread. r_1 is the radius of the thread core; the radius of the thread is r_0. MIxx × no. of threads = MI of the screw.

The data were tested by analysis of variance and pairwise comparisons of means to evaluate the holding power of the different screws and the different sectors of the femoral head. The moment of inertia was calculated for each screw (Figure 2). A linear regression analysis was performed to establish the relationship between the holding power and the moment of inertia.

Results

The Olmed screw had the greatest holding power, whereas the self-tapping prototype with short threads had the least holding power (Table 1). A statistical analysis divided the screws into three groups in which the means where not significantly different (Table 2).

Table 3 shows that the superior position was characterized by a greater holding power than either the inferior or the posterior position. On the other hand, the holding power in the anterior position was greater than in the inferior position. There were but marginal differences between the other positions.

The correlation between the holding power and the logarithmic transformation of the moment of inertia is illustrated in Figure 3 ($r = 0.94$, $P = 0.0002$). It could be be expressed as a formula,

$$HP = (1{,}654 \times \log MI \; -3{,}108) \text{ N},$$

where HP = holding power and MI = moment of inertia.

Discussion

The inability to control the backout of the fixation device is a problem (Gozna et al. 1982, Swiontkowski et al. 1987). When developing the new screw, a

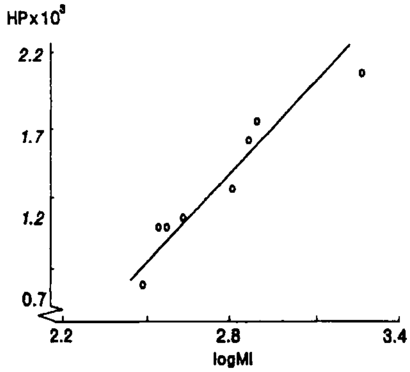


Figure 3. Scatter plot of HP versus log MI. HP = holding power, MI = moment of inertia. $r = 0.94$, $P = 0.0002$.

condition was that the pull-out strength of the implant had to be comparable to similar, currently used implants. Based on the results presented in Table 2, we decided that the two long-threaded prototypes were to be deemed acceptable, while the two short-threaded prototypes were excluded from further investigations.

In the present study, the holding power of screws placed in the four different quadrants of the femoral head was greatest superiorly, followed by the anterior and posterior positions, and lastly, by the inferior position. Iversen et. al. (1988) found that a screw placed in a central position in the head had a greater holding power when the tip was placed 12 mm from the chondral surface as compared with 4 mm. These results obviously reflect different trabecular densities in the different areas of the femoral head. Garden (1961) recommended that the screw should be positioned in a central position in the femoral neck and head. The posterior and inferior sectors have been regarded as acceptable, and the superior and anterior sectors as poor (Brown and Court-Brown 1979, Frandsen et al. 1979). These recommendations appear to be in conflict with the results of our study. Similarly, the findings of Iversen et al. (1988) seem to be in conflict with the recommendation of placing screws subchondrally in the femoral head (Rehnberg et al. 1988). However, the clinical importance of the holding power of the femoral head, as reflected by static pull-out tests, is not clear. Other factors seem to be clinically more important, such as the calcar support and the fact that most of the forces acting on an implant used for fixation of femoral neck fractures are, indeed, not axial traction forces (Pugh and Frankel 1985). Sufficient resistance to axial traction forces is important, but this has to be related to other properties of the implant.

Our experiments suggest that the holding power of a screw implanted in the femoral head is a function of the thread area and number of threads. The design of the threads may also have some importance. Some authors claim that the buttress shape has advantages over the V-shape (Gozna et al. 1982). This may be true owing to the effect of the biological properties of bone, which must always be borne in mind when interpreting experimental studies on bone resorption and remodeling.

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