COMBINED SURVIVORSHIP AND MULTIVARIATE ANALYSES OF REVISIONS IN 799 HIP PROSTHESES
A 10- TO 20-YEAR REVIEW OF MECHANICAL LOOSENING

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From 1970 to 1980 cemented metal-on-plastic total hip replacement was performed on 799 hips with primary osteoarthritis using one surgical technique. At the 10- to 20-year follow-up there had been 97 revisions for mechanical loosening.

Univariate survivorship analysis showed that an increased risk of revision was associated with male gender, young age at primary THR, the Brunswik and Lubinus snap-fit prostheses with large femoral heads (as compared with the Charnley prosthesis), and varying experience of the surgeon.

Multivariate statistical analysis showed a threefold increased risk of revision for men (p < 0.0001), an increase in relative risk of 1.8 per 10 years younger at surgery (p < 0.0001), a fivefold increase in risk for the Brunswik prosthesis (p < 0.0001) and a twofold increase for the Lubinus prosthesis (p = 0.0067). Inexperience of the surgeon, however, was not validated as a risk factor.

The study shows that the true risk factors for revision can be identified accurately by combining univariate survivorship and multivariate statistical analyses.

The importance of survivorship analysis of revision rates of hip prostheses with varying duration of follow-up has been well established since it was introduced by Dobbs (1980). This type of study, however, is a univariate analysis which cannot take into consideration any interfactorial influences. This leads to some uncertainty which is increased by the mixture of different diagnoses.

We have attempted to increase the validity of the long-term evaluation of different potential risk factors in an analysis of mechanical loosening of total hip replacements (THR) performed for the single diagnosis of primary osteoarthritis. We have validated the results of 10- to 20-year univariate survivorship analyses (Kaplan and Meier 1958) by a multivariate statistical analysis (Kalbfleisch and Prentice 1980). By this method it was possible to take into account both varying duration of follow-up and possible influences between the different risk factors.

PATIENTS AND METHODS
From 1970 to 1980 a total of 799 THRs with metal-on-plastic prostheses were performed for primary osteoarthritis. Three different types of prosthesis were used (Table I). There were 377 of the Charnley type with 22 mm heads, 151 of the Brunswik type with 35 mm heads and 271 of the Lubinus type with 32 mm heads. Both the Brunswik and the Lubinus types were snap-fit prostheses with polyethylene cups forming more than half a sphere. All three prostheses had a curved femoral stem which, in the Brunswik type, was wedge-shaped in section.

The cartilage was removed from the acetabulum; there was no meticulous preparation of the femoral canal. High-viscosity radiopaque polymethylmethacrylate cement was inserted without pressurisation and without distal plugging of the femoral canal. Prophylactic antibiotics were used in all except 38 patients at the beginning of the series (Ericson, Lidgren and Lindberg 1973). The 39 surgeons varied in experience and were grouped according to the number of THRs performed. A type-I surgeon had done 1 to 19 THRs; type II, 22 to 28; type III, 31 to 40; type IV, 117; and type V, 194. In the multivariate statistical analysis, the experience of the
surgeon was defined as the number of THRs performed before the operation under consideration.

Primary replacement for osteoarthritis was performed in 448 hips in 362 men of median age 66 years (36 to 87) and in 351 hips in 306 women of median age 67 years (47 to 84). Previous hip surgery had been performed in 45 hips (intertrochanteric osteotomy 32, soft-tissue release 7, fenestration of the femoral cortex 4, and acetabular roof surgery 2).

The Swedish national population registry enabled us to trace all 668 patients (799 hips) and to determine the date of death of 349 (419 hips). All surgical revisions were traced by combining information from the Swedish THR revision registry (Ahnfelt et al 1990), the hospital records and patient questionnaires. No patient was lost to follow-up and we obtained complete information about all deaths and revisions.

There was a total of 148 revisions (Table I) of which 97 were for mechanical loosening, 25 for infection and 26 for other causes such as early dislocation, late dislocation and fracture of the femoral component. We analysed only the 97 revisions for mechanical loosening. In a second identical analysis we studied only the first THR for each patient (668 hips).

Statistical methods. We used the Kaplan-Meier technique (Kaplan and Meier 1958) for univariate analysis of survival, defined as the prosthesis remaining in situ. Removal or replacement of one or both components for mechanical loosening was recorded as revision. Death of a patient, the date of final review, or surgical revision for causes other than mechanical loosening were recorded as withdrawals. The observation time for each THR was the period to the date of revision or withdrawal. The final review recorded the status of each THR on 31 December 1990. Statistical evaluation was by the generalised Wilcoxon test (Lee and Desu 1972) and was illustrated graphically in revision curves recognising that interpretation is increasingly uncertain at the tail-end of such curves (Dorey and Amstutz 1986). We then calculated the revision rates for different potential risk factors for mechanical loosening (Table II).

The accuracy of these univariate survivorship findings was validated by a multivariate statistical analysis, using Cox’s proportional hazards regression model (Kalbfleisch and Prentice 1980) including all the risk factors studied. This takes into account the possible interfactorial influences.

RESULTS

Of the 97 revisions for mechanical loosening, 67 hips had both prosthetic components revised (Charnley 14; Brunswik 37; Lubinus 16), 20 had only the femoral component revised (Charnley 12; Brunswik 2; Lubinus 6)

Table I. Main periods, numbers and number of revisions for three types of THR for primary osteoarthritis

<table>
<thead>
<tr>
<th>Prosthesis</th>
<th>Main time period</th>
<th>Number</th>
<th>Mechanical loosening</th>
<th>Other causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charnley</td>
<td>1970 to 1975</td>
<td>377</td>
<td>27</td>
<td>37*</td>
</tr>
<tr>
<td>Brunswik</td>
<td>1975 to 1978</td>
<td>151</td>
<td>43</td>
<td>6</td>
</tr>
<tr>
<td>Lubinus</td>
<td>1977 to 1980</td>
<td>271</td>
<td>27</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>1970 to 1980</td>
<td>799</td>
<td>97</td>
<td>51</td>
</tr>
</tbody>
</table>

* includes 25 infections in a randomised study of prophylactic antibiotics versus no prophylaxis (Ericson, Lidgren and Lindberg 1973)

Table II. Risk factors studied for revision for mechanical loosening of THR, giving their significance according to multivariate statistical analysis (Cox’s proportional hazards regression model)

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Variables</th>
<th>Relative risk</th>
<th>Confidence interval</th>
<th>p value</th>
<th>Occurrence of the variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male:female</td>
<td>3.0</td>
<td>1.9 to 4.9</td>
<td>&lt; 0.0001</td>
<td>448:351</td>
</tr>
<tr>
<td>Age at surgery</td>
<td>Per year younger</td>
<td>1.06</td>
<td>1.04 to 1.09</td>
<td>&lt; 0.0001</td>
<td>Continuous 36 to 87 years</td>
</tr>
<tr>
<td></td>
<td>Per ten years younger</td>
<td>1.8</td>
<td>1.4 to 2.4</td>
<td>&lt; 0.0001</td>
<td>Continuous 36 to 87 years</td>
</tr>
<tr>
<td>Type of prosthesis</td>
<td>Brunswik: Charnley</td>
<td>5.2</td>
<td>3.1 to 8.8</td>
<td>&lt; 0.0001</td>
<td>151:377</td>
</tr>
<tr>
<td></td>
<td>Lubinus: Charnley</td>
<td>2.3</td>
<td>1.3 to 4.2</td>
<td>0.0067</td>
<td>271:377</td>
</tr>
<tr>
<td>Experience of surgeon</td>
<td>Previous operations</td>
<td>–</td>
<td>0.998 to 1.007</td>
<td>NS*</td>
<td>Continuous 1 to 194</td>
</tr>
<tr>
<td>Previous hip surgery</td>
<td>Yes: no</td>
<td>–</td>
<td>0.1 to 1.1</td>
<td>NS</td>
<td>45:754</td>
</tr>
<tr>
<td>One or both hips operated</td>
<td>Unilateral:bilateral</td>
<td>–</td>
<td>0.6 to 1.4</td>
<td>NS</td>
<td>537:262</td>
</tr>
</tbody>
</table>

* not significant

Table III. Ten-year revision rates and confidence intervals (Greenwood 1926) of three types of THR evaluated by survivorship analysis (Kaplan and Meier 1958)

<table>
<thead>
<tr>
<th>Prosthesis</th>
<th>Revisions at 10 years (per cent)</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charnley</td>
<td>5.5</td>
<td>2.8 to 8.1</td>
</tr>
<tr>
<td>Brunswik</td>
<td>17.5</td>
<td>10.6 to 24.3</td>
</tr>
<tr>
<td>Lubinus</td>
<td>17.6</td>
<td>13.4 to 21.8</td>
</tr>
</tbody>
</table>
Graphs showing the cumulative percentage rates of revision for mechanical loosening: a) 448 hips in men and 351 hips in women (p < 0.0001); b) 118 performed at under 60 years of age, 363 at 60 to 70, and 318 at 70 or over (p = 0.0021); c) 377 Charnley, 151 Brunswik and 271 Lubinus (p < 0.0001); d) 183 performed by inexperienced (type I) surgeons, 234 by type II, 71 by type III, 117 by type IV and 194 by type V (p = 0.0172); e) 45 hips after previous surgery and 754 hips with no prior operation (p = 0.1482); and f) 537 unilateral and 262 bilateral THRs (p = 0.7426).

and 10 only the acetabular cup (Charnley 1; Brunswik 4; Lubinus 5).

Our univariate survivorship analysis of all 799 THRs showed an increased risk of revision for men as compared with women (Fig. 1a), for young age at primary surgery (Fig. 1b), for both the Brunswik and the Lubinus prostheses compared with the Charnley (Fig. 1c and Table III), and for differently experienced surgeons (Fig. 1d).

We found no difference between hips with or without previous surgery (Fig. 1e) or between unilateral and bilateral prostheses (Fig. 1f). Subsequent multivariate statistical analysis (Table II) confirmed the findings for gender, age (Fig. 2) and type of prosthesis but did not confirm the importance of the experience of the surgeon. Previous hip surgery and unilateral or bilateral THR were shown not to influence the revision rate.
DISCUSSION

By taking into account the varying duration of follow-up, survivorship analysis has provided a fairly true longitudinal picture of revision of THRs (Dobbs 1980). Many studies have been based on series with mixed diagnoses. Our study of revision for mechanical loosening only, in patients with a single diagnosis, a constant cementing technique and no loss to follow-up, must increase the accuracy of the findings (Carr et al 1993).

The use of univariate survivorship analysis, however, must introduce some uncertainty where studies include several variables. Univariate analysis does not consider the influence and interference of a given variable on other variables. This problem can be largely resolved by using multivariate analysis to determine the relative importance of different variables. This will validate or discard the stratified findings of univariate survivorship analysis. Some authors have used partial combinations of survivorship and multivariate analyses (Ritter and Campbell 1987; Visuri 1987; Morrey and Ilstrup 1989; Schurman et al 1989), but the predictive power of this statistical combination is optimised by beginning with univariate survivorship analysis of well-defined variables, and following this by a single multivariate statistical analysis of all these variables (Anderson et al 1980). In our study, the initial univariate analysis showed an increased risk of revision for four of six potential risk factors, but only three of these were validated as real risk factors by our multivariate statistical analysis.

Through the years, several designs of prosthesis have been abandoned when they have been found to give inferior results. An example is the Brunswik snap-fit prosthesis with a 35 mm femoral head (Lindberg and Carlsson 1983; Carlsson, Lindberg and Sanzén 1988; Johnsson, Thorngren and Persson 1988). Our study verifies its high revision rate for mechanical loosening. This is probably due to the combination of the snap-fit design causing traction and impingement between the head and the cup, the high frictional torque between the large femoral head and the cup, and the wedge-shaped stem splitting the cement (Lindberg and Carlsson 1983). The same pattern of revision is now obvious for the Lubinus prosthesis of the same snap-fit type with a large femoral head, but without a wedge-shaped stem. Failure of the Lubinus prosthesis with a 32 mm head was not apparent at a prior 4-year to 8-year follow-up (Johnsson et al 1988). It is still uncertain whether the increased mechanical loosening of these two types of prosthesis is due mainly to snap-fit constraint, increased frictional torque or (in the Brunswik) to the wedge-shaped stem. If snap-fit constraint or the wedged stem are the main reasons, the problem becomes historical because both concepts have largely been abandoned. If, however, the high frictional torque caused by a large femoral head is important, a significant long-term problem remains: 32 mm is still a common femoral head diameter (Ritter et al 1983; Morrey and Ilstrup 1989).

Our results confirm that the classical Charnley prosthesis with a 22 mm head maintains its place as one of the best functioning hip prostheses even without meticulous bone preparation or cement pressurisation (Fig. 3). Very similar results were reported by Schulte et

![Fig. 2](https://via.placeholder.com/150)

Relative risks of revision for mechanical loosening at different ages, taking THR at 65 years of age as 1 (Cox's proportional hazards regression model).

![Fig. 3](https://via.placeholder.com/150)

Well-functioning Charnley prosthesis 20 years after THR in a woman now aged 92. 

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al (1993) who followed 330 Charnley THRs (74% for osteoarthritis) for 20 years. Long-term survival rates will probably improve with modern techniques of preparation and cementing: mechanical loosening of the femoral component has been shown to decrease with modern cementing techniques (Mulroy and Harris 1990), but the problem of cup loosening is still unsolved. For patients with a high risk of mechanical loosening and revision, such as young men and revision cases, it is important that the quest for better fixation continues, such as the current ideas on 'fit and fill' (Horne 1992). For the most common candidate, however -- an elderly patient with primary osteoarthritis -- the effort to find a 'new and better' THR may be futile. Charnley's classical prosthesis has been shown to have an acceptable longevity.

Conclusions. Risk factors for revision for mechanical loosening of THRs including inferior prosthetic designs, can be identified accurately by the combination of long-term univariate survivorship studies with multivariate statistical analysis. In this way both varying duration of follow-up and possible interfactorial influences are considered. The classical cemented Charnley prosthesis with a 22 mm femoral head still maintains its position providing some of the best long-term results of THR for primary osteoarthritis.

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