An economic model to estimate the relative costs over 20 years of different hip prostheses

Kate Baxter, Gwyn Bevan

Abstract
Study objective—To determine the relative costs of prostheses and factors associated with changes in these cost rankings.

Design and setting—Economic model using published data.

Main results—The main cost drivers are current costs and revision rates. Expected revision costs are a small proportion of the expected total costs. There are few competitors to the “gold standard” Charnley in terms of total expected costs over 20 years. There is no monetary advantage in using higher cost prostheses in older patients even if they were to have lower revision rates. There may be a monetary case for using prostheses with higher costs and lower revision rates in younger patients.

Conclusions—The most cost effective prosthesis in older patients is the Stanmore. The Charnley, Exeter Polished and Muller Straight Stem are marginally more costly than the Stanmore. The study inevitably lacks good data on survival for newer prostheses. This does not affect the ability to make choices for older patients. Data are needed, however, on survival of cemented prostheses for younger patients.

(J Epidemiol Community Health 1999;53:542–547)

Total hip replacement has, since the 1960s, become one of the most frequently undertaken orthopaedic procedures in the National Health Service: there were 32 500 primary replacements undertaken in 1994/5. Total hip replacements are extremely effective in pain relief and improved physical function. The technology of hip prostheses is continually changing, with many new designs and methods of fixation. As total hip replacements have been extended to younger age groups, an increase in the longevity of implants is being sought. There is no statutory or nationally coordinated monitoring of processes of innovation and diffusion in the United Kingdom. Orthopaedic innovation in total hip replacement technology internationally has been referred to as a “trial and error culture” and there are over 60 different models of prosthesis used in the UK. There is a rising number of prostheses available, with little or no scientific evidence that the newer implants are any better than the established ones. The warning in February 1998 from the Medical Devices Agency about the unacceptably high failure rate of the 3M Capital hip system, combined with the fact that 4669 of these untested hips have been used in 95 centres throughout Britain, highlights this lack of regulation.

This paper describes the relative cost effectiveness of total hip replacements, based on total expected costs over 20 years, using a selection of hip prostheses available in the UK. The viewpoint taken is that of a purchaser.

We use a modified version of the model developed in papers by Daellenbach et al and Gillespie et al. Both these papers give the conditions necessary for cementless prostheses to be of equal or greater cost effectiveness than cemented prostheses. Both also stated concerns about the lack of adequate data on failure rates of established and newly developed prostheses. Extensive sensitivity analysis was carried out by Daellenbach et al on the cost parameters of the model where their accuracy was uncertain.

Pynsent et al introduced a new concept of “lifetime care packages”. With such a package, purchasers, rather than paying for subsequent revisions, would pay an insurance premium to providers at the time of the primary replacement, to cover the expected costs of revision.

Our paper adds to this previous work by using up to date hospital and prosthesis costs to give cost rankings for 15 prostheses. We also test the importance of each component of the model in estimating total expected costs and give simple graphs for comparison of total expected costs for hypothetical ranges of prosthesis prices and revision rates. The model can use new and local data as these become available.

Methods
COST MODEL

A model was developed to give the present value of using each prosthesis. The present value of prosthesis \( j \) is dependent upon three components: the costs of the initial prosthesis; hospital costs of the primary procedure; and the sum of expected future costs of revision. Future costs of revision depend on the age of the recipient and the survival of the implant. All future costs are discounted. The model is based on that used by Daellenbach et al and Gillespie et al and is of the form

\[
P_V = \sum_{j=1}^{15} \left( \frac{L\_{j} \cdot P_{j} \cdot (C_j + H + R)}{(1 + r)^t} \right)
\]

where
- \( PV_j \) = present value of using prosthesis \( j \)
- \( C_j \) = cost of prosthesis \( j \)
- \( H \) = hospital costs including separate categories for
  - theatre costs
  - ward costs
  - prophylaxis costs
  - physiotherapy costs
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- \( L_{mi} \) = probability of a person at age \( m \) when receiving a hip replacement being alive in year \( i \)
- \( P_{jmi} \) = probability of prosthesis \( j \) in person aged \( m \) needing to be revised in year \( i \)
- \( R \) = additional costs of a revision—that is, additional hospital costs
- \( 1/(1+r)^i \) = a discount factor where \( r \) is the discount rate, \( i=0 \) to 19 where 0 is the year of the primary operation

SENSITIVITY ANALYSIS
Sensitivity analysis is a method of dealing systematically with uncertainties in economic evaluations. It tests the robustness of the conclusions with respect to the data used. Simple sensitivity analysis is the most common, and entails changing one or more variables. One way analysis entails changing each variable individually to determine the effect on the final result of each variable. Multi-way analysis entails changing more than one variable, and can be used to consider different scenarios or “states of the world”.

The effect on total expected costs of each variable in the equation was tested using one way analysis. Total expected costs using a lowest and a highest possible value for each variable were compared with costs using the best estimate. The results indicate which variables have the greatest effect on total expected costs. The maximum and minimum values used in the sensitivity analysis are taken from either published data or data provided by the collaborating hospitals.

DATA SOURCES
Data used in the model were provided by two sources: two collaborating hospitals in different regions of England and published work.

The collaborating hospitals provided the average price they charged to purchasers for a hip prosthesis (\( C \)) in 1996/7. This allowed actual costs in the two hospitals to be modelled. Prosthesis prices quoted in Murray et al.
were also used to enable the model to compare expected costs of differing prostheses. Murray et al.
gives 1994 prices. These have been inflated using annual percentage price increases in hospital and community health services\(^{10}\) to provide data in the same base year as the hospital costs (1996/7). The well established and relatively cheap Charnley prosthesis has been used as the “gold standard” for the basic modelling and comparison against other prostheses. The range of market prices given by Murray has been used in the sensitivity analysis.

Hospital costs (\( H \)) were given by the collaborating hospitals, broken down into theatre, ward, physiotherapy, and prophylaxis costs. The effects of long and short theatre times and lengths of stay were examined through sensitivity analysis.

ASSUMPTIONS AND EXCLUSIONS
This model is based on a number of simplifying assumptions:

1. Prosthesis revision rates are linear where long term survival data are not known.
2. Mortality rates of total hip replacement recipients are equal to those of the general population.
3. Account is taken in the model of first revisions but not re-revisions.
Table 1  Present (cumulative) value of expected revision costs for men and woman for a selection of years (average hospital prosthesis and Charnley prosthesis costs separately)

<table>
<thead>
<tr>
<th>Year</th>
<th>Hospital A</th>
<th></th>
<th>Hospital B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Present value of expected costs (£)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prosthesis price</td>
<td>629*</td>
<td>370†</td>
<td>700‡</td>
</tr>
<tr>
<td></td>
<td>Primary replacement costs (exc prosthesis)</td>
<td>2985</td>
<td>2985</td>
<td>3479</td>
</tr>
<tr>
<td></td>
<td>Primary replacement costs (inc prosthesis)</td>
<td>3614</td>
<td>3355</td>
<td>4179</td>
</tr>
<tr>
<td></td>
<td>Cumulative expected costs of revisions(§)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>F</td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>by end of year 5</td>
<td>136</td>
<td>145</td>
<td>128</td>
<td>136</td>
</tr>
<tr>
<td>by end of year 10</td>
<td>244</td>
<td>278</td>
<td>209</td>
<td>262</td>
</tr>
<tr>
<td>by end of year 15</td>
<td>265</td>
<td>310</td>
<td>249</td>
<td>292</td>
</tr>
<tr>
<td>by end of year 20</td>
<td>297</td>
<td>371</td>
<td>279</td>
<td>349</td>
</tr>
<tr>
<td>Total expected costs</td>
<td>3911</td>
<td>3985</td>
<td>3634</td>
<td>3704</td>
</tr>
</tbody>
</table>

*Average prosthesis cost in hospital A, including cement (71). †Cost of Charnley prosthesis from Murray et al.3 High estimate = low estimate plus 1000.
‡Average prosthesis cost in hospital B. §Assuming revision rates of the Charnley prosthesis.

Table 2  Sensitivity analysis: effects on total expected costs of modelling minimum and maximum estimates of costs (women)

<table>
<thead>
<tr>
<th></th>
<th>Best estimate* (£)</th>
<th>Low estimate (£)</th>
<th>High estimate (£)</th>
<th>Total expected cost using low estimate (£)</th>
<th>Total expected cost using high estimate (£)</th>
<th>Difference in total expected cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prosthesis</td>
<td>370</td>
<td>336‡</td>
<td>1336‡</td>
<td>3667</td>
<td>4523</td>
<td>1056</td>
</tr>
<tr>
<td>Time in theatre</td>
<td>144 mins</td>
<td>60 mins‡</td>
<td>246 mins‡</td>
<td>2932</td>
<td>4642</td>
<td>1710</td>
</tr>
<tr>
<td>Days on ward</td>
<td>13.2 days</td>
<td>9 days‡</td>
<td>22 days‡</td>
<td>3096</td>
<td>4978</td>
<td>1882</td>
</tr>
<tr>
<td>Discount rate</td>
<td>5%</td>
<td>6%</td>
<td>0%</td>
<td>3680</td>
<td>3881</td>
<td>201</td>
</tr>
<tr>
<td>Additional revision costs</td>
<td>19%</td>
<td>0%</td>
<td>100%</td>
<td>3644</td>
<td>3902</td>
<td>258</td>
</tr>
<tr>
<td>Recipient age</td>
<td>70 years</td>
<td>80 years</td>
<td>40 years</td>
<td>3568</td>
<td>3876</td>
<td>308</td>
</tr>
<tr>
<td>Annual revision rate¶</td>
<td>variable 0.5% to 3%</td>
<td>1%</td>
<td>5%</td>
<td>3722</td>
<td>5191</td>
<td>1469</td>
</tr>
</tbody>
</table>

*Best estimates from hospital A’s costs and Charnley prosthesis price and revision rate. ‡Low estimate from Murray et al., high estimate = low estimate plus 1000. ¶Data from hospital A. †Data from Trent Region 1990. | Data from Pynsent et al. | *Best estimate based on actual Charnley revision rates, which vary from year to year, high and low estimates based on 1% and 5% per annum revision rates.

Results

Table 1 gives the present value of expected revision costs over 20 years, separately for men and women aged 70 at replacement. Charnley revision rates calculated from published sources (range 0.5% and 3% revisions per year) are used. Two prosthesis prices are used for each hospital: the prosthesis prices charged by the respective hospitals, and the cost of a Charnley from published data. The prosthesis prices quoted by the hospitals are average prices of prostheses. The mix of prostheses that these averages represent is not known. However, from a purchasers point of view, the charge is part of the standard price of a total hip replacement. These hospital prosthesis prices are higher than the price of a Charnley given in Murray et al.3 Results using both prices are therefore included to show the actual as well as the possible costs. Primary replacement costs, the present value of cumulative expected costs of revisions (shown at five year intervals), and total expected costs are shown. Expected revision costs over 20 years for women are slightly higher than for men.

For male patients in Hospital A, using the hospital’s own data, the expected cost of revisions over 20 years is £297. The total expected costs are therefore the primary replacement costs plus the £297. If a hypothetical new prosthesis needed no revisions over 20 years, its expected cost would be equal to its primary replacement costs. A purchaser would therefore be prepared to buy this “no revisions” prosthesis if its cost was no more than £297 greater than the current prosthesis. Paying more than £297 extra (that is, £296 in total) for the “no revisions” prosthesis would result in the costs over 20 years being greater than the costs using the current implant. Using data for Hospital B, the maximum extra a purchaser would be prepared to pay for a “no revisions” prosthesis is slightly higher at £344 (£973 total).

For simplicity, the equation used in the sensitivity analysis and the comparison of different

Table 2  Sensitivity analysis: effects on total expected costs of modelling minimum and maximum estimates of costs (women)
Table 3  Relative cost effectiveness of the Charnley and 15 comparison prostheses—best, low, and high estimates (women)

<table>
<thead>
<tr>
<th>Make/type</th>
<th>Prosthesis price</th>
<th>Prosthesis survival at 20 years (%)</th>
<th>Best estimate</th>
<th>Low estimate</th>
<th>High estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charnley*</td>
<td>370</td>
<td>78</td>
<td>3704</td>
<td>2323</td>
<td>5916</td>
</tr>
<tr>
<td>Cemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stanmore**</td>
<td>373</td>
<td>88</td>
<td>3578</td>
<td>2247</td>
<td>5712</td>
</tr>
<tr>
<td>Muller straight stem****</td>
<td>424</td>
<td>80</td>
<td>3696</td>
<td>2341</td>
<td>5869</td>
</tr>
<tr>
<td>Exeter Polished**</td>
<td>431</td>
<td>82</td>
<td>3718</td>
<td>2387</td>
<td>5899</td>
</tr>
<tr>
<td>Cemented alumina-alumina (age &lt;50)***</td>
<td>516</td>
<td>89</td>
<td>3780</td>
<td>2429</td>
<td>5943</td>
</tr>
<tr>
<td>Howse**</td>
<td>516</td>
<td>70</td>
<td>3976</td>
<td>2554</td>
<td>6255</td>
</tr>
<tr>
<td>McKee-Farrar*</td>
<td>516</td>
<td>49</td>
<td>4061</td>
<td>2667</td>
<td>6389</td>
</tr>
<tr>
<td>Cemented alumina-alumina (age &gt;50)***</td>
<td>516</td>
<td>81</td>
<td>4190</td>
<td>2689</td>
<td>6954</td>
</tr>
<tr>
<td>Lubinou IP****</td>
<td>516</td>
<td>88</td>
<td>3741</td>
<td>2405</td>
<td>5882</td>
</tr>
<tr>
<td>CAD****</td>
<td>516</td>
<td>86</td>
<td>3767</td>
<td>2422</td>
<td>5924</td>
</tr>
<tr>
<td>Lubinou SP*****</td>
<td>808</td>
<td>93</td>
<td>3946</td>
<td>2645</td>
<td>6029</td>
</tr>
<tr>
<td>Spectron****</td>
<td>808</td>
<td>91</td>
<td>3971</td>
<td>2662</td>
<td>6068</td>
</tr>
</tbody>
</table>

Total hip replacement: a model of the costs

![Figure 1](http://example.com/figure1.png)  
**Figure 1**  Relative costs over 20 years for a range of prosthesis prices and revision rates for female recipients aged 70 years (discount rate 5%).

![Figure 2](http://example.com/figure2.png)  
**Figure 2**  Relative costs over 20 years for a range of prosthesis prices and revision rates for female recipients aged 40 years (discount rate 5%).

Notes: All prosthesis prices from Murray et al. Where specific prices not quoted, average price of cemented (516) or cementless (1205) prostheses used as appropriate. $20$ year survival rates estimated from published sources. Best estimates from hospital A’s costs and Charnley prosthesis price and revision rate. Low estimate (theatre 60 mins and ward 9 days), high estimate (theatre 246 mins and ward 22 days) (from table 2).

*Revision data available for 20 years. **Revision data available for 15–19 years, then extrapolated. ***Revision data available for 10–14 years, then extrapolated. ****Revision data available for 5–9 years, then extrapolated. *****Revision data available for <5 years, then extrapolated.

prostheses models costs from only one hospital (Hospital A) with Charnley survival rates and Charnley prosthesis price.

Table 2 gives the results of the sensitivity analysis that examined, independently, the impact on expected costs of each of the following: prosthesis price, time in theatre, length of stay on ward, discount rate, revision costs, recipient age, and revision rate. The main cost drivers—that is, those which have the biggest impact on total expected costs—are shown to be hospital (theatre and ward) costs, price of prosthesis, and revision rate.

Table 3 models the relative costs of a range of competing prostheses with the Charnley as the “gold standard”. The minimum and maximum estimates of hospital costs used in the sensitivity analysis were modelled to show any impact on cost rankings. Prostheses are classified by the number of years survival data available. Where $20$ year actual survival data are available, this is indicated by a single asterisk (*), data for less than five years is shown by five asterisks (*****). Survival data for all prostheses were extrapolated to $20$ years. The effect of extrapolating limited prosthesis survival data is considered in the discussion. Where prosthesis prices were unknown, these were assumed to be equal to the average price paid by Hospital A. The Stanmore prosthesis appears to be marginally less costly over $20$ years than the Charnley, the Exeter Polished and Muller Straight Stem, which are of similar expected costs. All four of these prostheses have prices of about £400. All the cementless prostheses have expected costs over $20$ years of around £700 more than a Charnley and all are more costly than any of the cemented prostheses. Figures 1 and 2 show expected total costs over $20$ years for combinations of differently priced prostheses and revision rates for 70 and 40 year old female recipients respectively.
Discussion
This research has modelled the long term costs of different prostheses. There are currently over 60 different types of prosthesis used in the United Kingdom, with significant variation in price. Although reasons for consultant choice may include knowledge of prosthesis survival and function in situ, interviews with surgeons indicate that manufacturers exert a degree of influence over surgeons’ preferences, with some orthopaedic departments being supplied by a single manufacturer. This paper makes explicit the costs associated with a range of prosthesis prices and performance.

We present the main conclusions based on our stated assumptions. We then examine how these conclusions might alter with changes in these assumptions. Finally, we discuss our findings in relation to previous work and suggest an area for future research.

Our main conclusions are:

- Compared with Charnley survival data from “centres of excellence” and prosthesis cost of £370 including cement, a “no revisions” prosthesis should cost not more than about £700 to have equivalent total expected costs over 20 years. (This result is in agreement with Daellenbach et al. who showed that the price of prostheses with low failure rates can be only marginally higher than those with higher failure rates for the present value of expected future costs to be comparable.)
- Prosthesis cost, hospital costs and the revision rate are the main cost drivers of total expected costs.
- Given the data used in the model, the Stanmore prosthesis appears to be less costly over 20 years than the Charnley; the Exeter Polished and Muller Straight Stem have similar expected costs.
- Very high and very low estimates of hospital costs change the total expected costs to levels above those assumed will increase total expected costs. Cost rankings will also be changed if rates of revision of prostheses change relative to each other.
- We also assumed that people who have had a hip replacement at a mortality rate equal to the general population for their age group. If, as Malchau et al suggest, these people have on average a lower life expectancy, total expected costs would be lower than estimated here because of the greater number of people dying before their prosthesis needs replacing. It is possible, however, that younger patients may be a more active group than the general population and therefore have a higher life expectancy. More information is needed before the true impact on costs of life expectancy can be known.
- Increases (decreases) in prosthesis costs used to increase (decrease) total expected costs. Changes in prosthesis prices relative to each other may also change relative costs. Costs at specific hospitals can be modelled to allow for differences in manufacturers’ prices.

We did not calculate costs occurring after 20 years. For elderly patients, the discount factor combined with the high mortality rate means that expected costs in 20 years time are negligible (£0.35 in the 20th year after primary implant). However, for young patients, the low mortality rate and the increasing total hip replacement revision rate over time mean that a high proportion of younger people will survive longer than their implants. Despite the discount factor, the expected costs for a 40 year old recipient in the 20th year after primary implant are still relatively important (£26.48). This difference must be considered when comparing results across age groups.

Pynsent argues that a premium of 9% for 75–84 years olds (20% for 65–74 year olds) should be charged for “lifetime” (20 year) insurance for the Charnley prosthesis. From our model, the premium for 70 year olds would be around 10% for the Charnley (expected revision costs of £349 for a primary replacement of £3355, table 1). For prostheses with
higher expected rates of revision, the premium would be a proportionately higher percentage of primary replacement costs (16% for McKee-Farrar and 22% for AML). We agree with Pyntsen that a “lifetime” care package should encourage monitoring of prosthesis survival rates and setting of prices to reflect these rates. However, with hospital costs, prosthesis price, and revision rates as the components having the greatest effect on expected costs, such a proposal would be risky for providers (who would offer the package to purchasers). While providers have good knowledge of their own costs and the prices charged for prostheses, they would be required to set premiums based on information from manufacturers on prosthesis revision rates. Lack of published data and poor knowledge of long term revision rates may encourage reliance on established prostheses and thus stifle new developments. A solution would be to require all new prostheses to undergo long term clinical trials before release onto the market. EC directives state that, by June 1998, hip prostheses used in the UK (among other implants) should carry a “kite mark” showing Medical Devices Agency approval.18 This will not be as rigorous as clinical trials for drugs (which can take up to 10 years before being granted a licence), but is a first step.15

Despite data of variable quality and limited data on important characteristics, such as long term survival of prostheses, the approach outlined in this paper, based on total expected costs, assists decisions on choice of prostheses by making explicit those factors affecting total expected costs. The use of up to date hospital costs, combined with available (table 3) and potential (figures 1 and 2) revision rates, enables new prostheses to be assessed against those for which we have good data, and allows new assessments to be made relatively easily as data become available.

This paper has not investigated the effects on patients’ quality of life of different prostheses, or of repeated and early revisions. An interesting area for future research would be to combine prosthesis survival and quality of life data to make these comparison.

We thank the staff at the two collaborating hospitals for supplying cost data and other information for use in this model. We also thank the authors of the systematic review of which this paper is a small part: Alex Faulkner, Gail Kennedy, Jenny Donovan, Mark Wilkinson, Ian Learmonth and Paul Gregg. Thank you also to two anonymous referees who supplied helpful comments on an earlier draft.

Funding: National Health Service Research & Development Health Technology Assessment Programme of England and Wales.

Conflicts of interest: none.

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*J Epidemiol Community Health* 1999 53: 542-547
doi: 10.1136/jech.53.9.542

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