IN BRIEF

- The most cost-effective large restorations placed in this study were posterior amalgams and anterior resin composites.
- The benefits of direct placement restorations also include less discomfort and less removal of sound tooth substance with fewer biological consequences.
- There was no support found for the practice of replacing large amalgam and resin composite restorations with crowns to prevent potential tooth fractures.
- Where indirect posterior restorations were thought necessary, full gold then ceramometal crowns were more cost-effective than cast gold onlays.
- Similarly, for indirect anterior restorations, ceramomental crowns were more cost-effective than porcelain jacket crowns.

Long-term cost-effectiveness of single indirect restorations in selected dental practices

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Objective To determine the relative cost-effectiveness of alternative methods for restoring large tooth substance loss in adults.
Methods Long-term survival estimates and discounted costs for 245 large indirect restorations were used to calculate their incremental cost-effectiveness over 15 years when compared with direct placement Class II cusp-overlay amalgams and Class IV multisurface resin composites, placed in 100 patients from three private dental practices.
Results The direct placement restorations were more cost-effective than the indirect restorations at all time intervals over the 15-year study period. The full gold crown and the ceramometal crown were the most cost-effective indirect posterior and anterior restorations respectively. The cast gold onlay and the porcelain jacket crown were the least cost-effective indirect posterior and anterior restorations respectively.
Conclusions When clinically practicable, large direct placement restorations should be placed initially in preference to indirect restorations.

INTRODUCTION

Despite the continued urging in recent years for more economic evaluations in dentistry,[1] and more evidence-based dentistry,[2] there is remarkably little information available regarding the cost-effectiveness of different restorative materials and treatments undertaken for the same patient populations in private dental practices.[3] The little information that is available is largely based on estimates of restoration survivals and costs from widely differing populations and on speculations on future, long-term restoration retreatments and their relative costs.[4-9]

Most economic studies of cost-effectiveness have been of poor quality,[10] and no valid comparisons of the cost-effectiveness of different restorative materials placed in dental practices in the same patient populations have been published to date. Significantly, when different restorative materials or treatments are recommended by practitioners, evidence-based treatment information is becoming increasingly important for the legal requirements of informed patient consent.[11] Third party funding providers also have a responsibility for the most effective use of limited healthcare resources.[12] Therefore, the aim of the present retrospective case control study was to examine the long-term cost-effectiveness of commonly used types of anterior and posterior single indirect restorations placed in selected private dental practices, and to compare the findings with those for two types of less expensive direct placement restorations.

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MATERIALS AND METHODS

The study was designed to meet stated criteria for the economic evaluation of alternative dental restorative treatments.[13] Approval for the study was obtained from the Human Research Ethics Committee of The University of Adelaide.

Information on the survivals of single full gold crowns (FGCs), anterior and posterior ceramometal crowns (CMCs), porcelain jacket crowns (PJCs), and cast gold onlays was obtained during 1995. The information was gleaned from the case note records of 100 patients who were treated in three long-established busy private dental practices in metropolitan Adelaide, South Australia. All patients had continuous treatment records ranging from a minimum of 10 up to 37 years, with all restorations placed before January 1985. The 100 records were selected as meeting the minimum restoration observation period of 10 years; from the examination of 3,140 case notes obtained by hand searching the practice filing systems and using prime numbers as a semi-random method for determining which drawers to search.

These records generated data for 345 indirect restorations that were encoded in a database (Access 2.0, Microsoft Corp., Redmond, WA, USA). The data were subject to error detection subroutines before life table survival estimates were generated for the different restoration types using BMDP statistical program 1L.[14] Apparent failures caused by reasons unrelated to the restorations were treated as censored information in the statistical analysis.[15] Such failures included the replacement of sound restorations by bridge abutments, damage to restorations caused by access for endodontic treatments, and extraction of teeth for periodontal reasons. Survival estimates for the indirect test restorations were also compared with those for direct placement Class I amalgams (the global reference restoration), Class II MOD amalgams with two cusps overlaid with amalgam (for comparison with posterior crowns and cast onlays), and Class IV bonded resin composites with three or more surfaces involved (for comparison with anterior crowns). The data for these three reference restorations came from two of the same dental practices used in the present study.[3,16] Because the very long survivals of the FGCs, CMCs and Class I amalgams did not allow for the calculation of their median survival estimates, the percentages of all restoration types surviving at 5, 10 and 15 years were used instead for the subsequent incremental cost-effectiveness analysis.

The actual billed costs for all restorations at the times of their placement were also recorded. Discounting is a process used to estimate future costs as if they occurred in the present. It accounts for rising prices over time. The discount rates for each restoration type at different intervals over the study were calculated by using the formula:

$r = ((S/P)^{1/N})-1$,[17] where:
r = the rate of discount (x100%)
S = the replacement cost of the restoration
P = the original cost of the restoration
N = the number of years until the expense is incurred

The calculated restoration replacement costs in 1992 were based on the means of the central 80% (less any zero charges) of responses obtained from South Australian metropolitan dentists in the 1992 Australian Dental Association fee survey, as used in a previous study.[3] The annual discount rate for the three reference restorations (Class I and II amalgams, Class IV resin composite) was set at 9.66%, which was the median derived from all of the other test restorations in the present study where the rates were usually between 8% and 12% and included varying rates of inflation.

Cost-effectiveness analysis is a technique used to evaluate the ability of alternative uses of limited resources to maximise defined objectives.[18] Desirable outcomes are not valued in monetary terms, but in some other unit. In healthcare analyses, one measure is years-of-life-saved. Comparisons may be stated in terms of cost per unit effect, such as costs per restorative life-year. In the present study, because no definition of cost-effectiveness for dental restorative treatments was found in the literature, a cost-effective dental restorative treatment was defined as one that repeatedly and predictably gives a desirable length of service in defined circumstances for the least net cost per unit of effectiveness (survival). For each time period at 5, 10 and 15 years, the incremental cost-effectiveness (CEA) of one test restoration type (A) relative to another reference restoration type (B) is the difference in the discounted costs incurred, divided by the difference in their effectiveness or change in outcome (restoration survivals), using the formula; Incremental CEA = Discount cost (A-B)/Effectiveness (A-B).[17] The results in the present study were expressed as the net costs (A$) for each percentage unit increase in test restoration survivals. The lower the values then the higher are the benefits derived.

A sensitivity analysis was used to test the robustness of the results. When using a sensitivity analysis, the most uncertain features and assumptions in a cost-effectiveness result are varied one at a time over a wide range of possible values. If the basic conclusions of the study do not change, then confidence in them is increased.[18] Therefore, comparisons were made between the crown data from the present study and the crown and reference restoration data from the earlier study by Hawthorne.[16] The discount rate (r) was the only estimate that could be subject to debate as all other factors were fixed. Therefore, this rate was varied between 1%, 5%, 10% and 15% for all time periods, to change the cost increments and the incremental cost-effective ratios.

To assess the accuracy of the original data transcriptions, 15 of the original case note records were again selected from the three practices in a ratio of 10, 3 and 2, using a random selection method. The duplicate recordings were undertaken long after the original data collection. A low error rate of 3.3% included failures to record dates of birth in three instances and a minor treatment in one instance. Others included transcription errors which were irrelevant to the study analysis.

RESULTS

There were no significant differences found between the three dental practices in the distribution of patients by gender or age groups ($p > 0.20$). There was also no significant difference in the distribution of restorations by age groups ($p = 0.07$). The mean age of all patients at the time of restoration placement was 40.41 ± 11.97 (SD) years. Nine dentists placed the 345 indirect restorations involved. However, all of the relatively few cast onlays and PJCs were placed by one very skilled dentist, in one practice. The 18 PJCs were essentially limited to restoring maxillary incisors, and the 93 FGCs to restoring molars, usually mandibular. Most of the 212 CMCs restored maxillary incisors and premolars, and the 22 cast onlays were fairly evenly distributed between canines, premolars and molars. Over the study period, PJCs and cast onlays were rarely replaced more than once by the same type of restoration, while FGCs and CMCs were more likely to be replaced more than once by the same restoration type.

The abbreviated life table cumulative survival estimates for the different test restorations and the three reference restorations are shown at 5, 10 and 15 years in Table 1. The FGCs, CMCs and Class I amalgams had the longest, and the cast onlays the lowest percentage survivals. The median survival times for the FGCs, CMCs and the 269 Class I amalgams could not be estimated, but all exceeded 20 years. The 93 anterior and the 119 posterior CMC cumulative survivals were very similar ($P > 0.05$). The median survival times were 9.8 (0.33 SEr) years for cast onlays, 15.9 years for PJCs, 14.6 (1.2 SEr) years for the 160 Class II cusp-overlay amalgams, and 12.7 (1.6 SEr) years for the 57 Class IV multisurface resin composites. None of the cast onlays survived until 15 years, usually failing because of recurrent caries. Bulk fracture was a significant cause of failure for the PJCs.

Table 1 Percentage survival estimates for restorations

Type	5 years	10 years	15 years
FGC	95.4 (2.2)	92.8 (2.9)	86.0 (4.6)
CMC	93.6 (1.8)	88.2 (2.4)	76.9 (4.3)
Cast onlay	72.7 (9.5)	40.8 (15.1)	Nil
PJC	94.1 (5.7)	66.6 (14.0)	66.6 (14.0)
Class I amalgam	91.3	85.8	82.5
Class II cusp amalgam	77.6 (4.4)	65.0 (5.3)	47.8 (7.0)
Class IV resin comp.	63.0 (7.7)	56.3 (9.3)	47.7 (11.2)

Shaded area denotes restoration data from Hawthorne.[16] The standard errors of the means are shown in parentheses

The calculated discount costs at selected times for the different restorations are shown in Table 2. These discount costs are very accurate for those restorations and times shown in the unshaded area of the table, but are based on either extrapolations or dental practice estimates from the 1992 South Australian survey figures for those restorations and times shown in the shaded area.

Table 2 Discounted costs for restorations (A$)

Type	1992	1990	1985	1980	1975	1958
FGC	650.0	513.6	285.0	158.2	87.8	15.0
CMC	695.0	569.7	346.6	210.9	128.3	28.9
Cast Onlay	375.1	280.5	135.6	65.5	31.7	12.7
PJC	606.4	535.6	392.8	288.0	211.2	73.6
Class I amalgam	50.0	41.6	26.2	16.5	10.4	2.6
Class II cusp amalgam	115.0	95.6	60.3	38.0	24.0	6.0
Class IV resin comp.	82.0	68.2	43.0	27.1	17.1	4.3

Shaded area denotes estimated costs for restorations. The 1992 cost figures were from the ADA South Australian Dental Practitioner Survey[3]

Table 3 Incremental cost-effectiveness ratios for all restorations relative to the Class I amalgam restoration

Type	5 years	10 years	15 years
FGC	113.2	36.9	40.0
CMC	245.1	160.3	[-49.6]
Cast onlay	[-12.9]	[-2.4]	Nil
PJC	173.4	[-19.1]	[-17.0]
Class II cusp amalgam	[-3.9]	[-1.6]	[-0.4]
Class IV resin comp.	[-0.94]	[-0.6]	[-0.3]

Values within parentheses denote that the restoration effectiveness (survival), but not the cost, was less than the Class I amalgam

The incremental cost-effectiveness ratios for all test restorations relative to the Class I amalgam restoration are shown in Table 3. In all instances, the test restorations were less cost-effective than the global reference restoration. The incremental cost-effectiveness ratios for the posterior test restorations relative to the Class II cusp-overlay amalgam restoration are shown in Table 4. Again, the test restorations were less cost-effective than the posterior reference restoration, although the cost-effectiveness improved over time for the FGCs and CMCs, but not for the cast onlays. Similar ratios for the anterior test restorations relative to the Class IV multisurface resin composite restoration are shown in Table 5. Again, the test restorations were less cost-effective than the anterior reference restoration, although the cost effectiveness of the CMCs improved with time. After 15 years, the cost-effectiveness of the PJCs remained essentially unchanged from 5 years. The lack of improvement in their cost-effectiveness at 10 years was due to a decrease in their survivals (effectiveness) at this time. Thereafter, the remaining PJCs continued to survive until the 15-year period.

For the sensitivity analysis, varying the discount rates did not affect the cost-effective rankings between the test and reference restorations, except for the Hawthorne crowns,[16] for which the data were not as sensitive as those used in the present study. At 15 years, the discount rate, including inflation, for the FGCs was between 10% and 15% and, for all other restorations, between 5% and 10%. These findings support the discount rates used in the present study as being realistic.

DISCUSSION

The three private dental practices involved were selected because they were long-established, busy and centrally located. However, the findings from these practices are not necessarily the same as those from similar private practices either in Adelaide or elsewhere.

Decision analysis and cost-effectiveness analysis attempt to develop criteria for allocating resources by using existing clinical practice information. Such approaches have potential value both for allocation decisions within a health category and across diseases or health problems.[18] Cost-effectiveness analysis poses the question '*What is the least expensive way of achieving a stated objective*'? In this case the objective being the longest survivals of large anterior and posterior dental restorations placed in selected private practices. The analysis does not attempt to establish the relative benefits, from both the dentists' and patients' viewpoints, of other quality outcomes or utility values of alternative restorative treatments.[12] These benefits could include improved function and appearance, less discomfort, complications and time involved, and less sound tooth substance removed with fewer biological consequences.[19]

The aim of restorative treatment is to maintain the dentition, and restorations may be replaced by similar or other types many times before the teeth are lost, often for unrelated reasons. Although restoration survival is an intermediate health outcome, it is assumed to relate strongly to the final health outcome: tooth retention.[13] The generally high survival times for the restorations placed in the three private practices (Table 1) compare well with the results from other studies,[20] and probably indicate good quality dentistry that was largely or entirely paid for by satisfied long-term patients. However, high survival times lead to problems in determining the median survival times for some types of restorations, as it is difficult to obtain records for the continued attendance of patients in the same practice over a 30-40 year span. To overcome this problem, the incremental cost-effectiveness was undertaken at 5, 10 and 15 years after placement of the restorations. These intervals may also be of more interest to practitioners than a single cost-effective ratio based on differing median intervals.

Table 4 Incremental cost-effectiveness ratios for posterior restorations relative to the Class II cusp-overlay amalgam restoration

Type	5 years	10 years	15 years
FGC	23.4	8.1	3.1
CMC	31.7	15.6	8.9
Cast onlay	[-38.3]	[-3.1]	Nil

Values within parentheses denote that the restoration effectiveness (survival), but not the cost, was less than the Class II cusp-overlay amalgam

Table 5 Incremental cost-effectiveness ratios for anterior restorations relative to the Class IV multisurface resin composite restoration

Type	5 years	10 years	15 years
CMC	17.5	11.9	9.2
PJC	15.0	34.3	13.8

The actual costs of the restorative treatments and the management of any complications were assumed to reflect the dentists' fees, and excluded the opportunity costs of lost income and productivity from patients taking time off from work and other activities. The much higher placement costs for the indirect test restorations may have also included a higher profit margin than when placing large amalgams and anterior resin composites over the same clinical time. Although there are wide variations in the placement costs for different restoration types in different countries and dental practices, the restoration cost rankings appear to be very similar.[3,7,21]

The discount costs calculated for the test restorations show that it is simplistic to assume that the discount rate is the same for all restoration types, and that it remains constant for any type of restoration across all time periods (Table 2). The discount rate was higher for cast onlays (15.7%) than for CMCs (10.5%) during the same 10-year period (1975-1985), and higher for FGCs (7.7%) than for CMCs (3.1%) during the more recent same 8-year period (1985-1992). It was assumed that the actual fees charged at different time periods were adjusted for inflation by the practitioners.

The most universal standard dental restoration, or global reference restoration, is the Class I amalgam. It has the longest reported survivals of all commonplace restorations to date, and can be used as a cost-effective benchmark to compare all other restorative tooth treatments. In the present study, when compared with the other indirect test restorations, the FGC was the most cost-effective restoration at all time intervals (Table 3). The individual circumstances for the placement of the crowns were unknown, and this finding does not mean that FGCs are the most appropriate restorations in all clinical situations where large restorations are required.[22] Crowns may have been selected instead of direct restorations for aesthetic reasons or where the teeth had lost substantial amounts of sound tooth structure. The more expensive CMC also had slightly lower survival rates than the FGC, which therefore reduced its cost-effectiveness at all time intervals.

The findings from the present study for posterior restorations (Table 4), and from other studies on the long-term survivals of extensive amalgam restorations,[23-25] support the conclusion from an earlier theoretical study that a failed large first amalgam should be replaced by another similar amalgam rather than by an indirect crown.[5] The present study findings also did not support the widespread replacement of large amalgams by crowns for preventing potential tooth fracture, or to provide more permanent cost-effective treatment measures.[3,26] The relatively poor cost-effective performance of the cast onlays probably reflects to some extent the reason for their current decreased usage in general practice. However, patients are also now more likely to request tooth-coloured restorations than gold castings to restore anterior and posterior teeth.

The present study also found that an anterior PJC was slightly more cost-effective than a CMC at 5 years, but not over the longer term (Table 5). As both restorations were less cost-effective than a large Class IV resin composite, it may also be preferable to replace such a failed first restoration with a similar resin composite before placing an indirect crown. The placement of aluminous PJCs has now been largely supplanted by CMCs in general practice.

Attempts have also been made in several studies to predict the lifetime cost-effectiveness of various restorative treatments. However, as stated previously, these attempts have been based largely on restoration survivals and costs data derived from widely differing populations, together with considerable conjecture on the long-term natural history progression of retreatments.[3] In none of these studies was cost discounting used, based on the actual fees charged for the restorations at the time of their placement, or a sensitivity analysis undertaken. Apart from one previous study,[16] only one other study has attempted to obtain from dental practices some limited restoration failure data, that were then used to determine the long-term costs of various restorations placed in the UK.[9] However, the numbers of amalgam, resin composite and glass ionomer restorations were deemed by the authors to be too few to allow for subdivision of the failures by class of cavity preparation, which obviously has a very significant effect on restoration survivals. Estimates were then made, based on this local information and that from other population studies, for the median longevity of small (one surface) and large (MOD type) restorations in general practice in the UK, including gold inlays. Information on the relatively high fees charged for Class II direct resin composites was obtained by telephoning local practitioners, as these restorations were not included under National Health Service Regulations.

The relatively lower restoration survival times generally selected for several studies,[6,7,9] as compared with the actual restoration survival times found in the present and another related general practice study,[3] significantly influenced the theoretical replacement rates for the restorations over a 60-year span, from 15 to 75 years of age during a person's lifetime. Theoretically, in the present study, the various large direct and indirect restorations would be replaced between approximately 2.5 and 6 times over 60 years, as compared with between approximately 3.5 and 20 times for the large amalgams, resin composites and cast gold restorations from the three other studies.[6,7,9] If the survivals and cost estimates from the present study are applied in the same theoretical manner as used by Mjör,[7] then the following net increases in costs over a 60-year span are generated. The FGC is 3.4 times, the posterior CMC is 3.6 times, and the cast gold onlay 4.6 times more expensive than the Class II cusp-overlay amalgam. The anterior CMC is 5.1 times, and the PJC is 5.9 times more expensive than the Class IV multisurface resin composite. There are decreasing lifetime net costs for the FGCs, CMCs and PJCs relative to the two reference restorations, up until the last 15 years of the 60-year span, when the final crown replacements at around 60 years of age greatly reverse this trend. Therefore, cost-effective ratios for indirect crowns do not necessarily continue to improve throughout a patient's lifetime.

In the present study, the median survival time of 9.8 (0.33 SEr) years found for the 22 cast onlays is considerably less than the 18 years selected by Mjör *et al.*[9] for large cast gold inlays placed in general practice in the UK. This latter figure appears high when compared with the median survival times selected for such castings in other similar cost studies,[6,7] and also relative to the rather low figures selected for the estimated longevity of other direct restorations placed in the UK.[9] Earlier UK studies of cast inlays have found median survivals of 7 years[27] and less than 10 years.[28] Because of the high, selected median survival figure of 18 years for cast inlays placed in UK general practices,[9] the theoretical increased costs over 60 years for a large three-surface cast inlay was only approximately 2.5 times that of a similar amalgam, as compared with the 4.6 times increase found in the present study. One other similar Norwegian study analysis suggested a four-fold increase in these costs when comparing large cast inlay and amalgam restorations, where the median longevity of the large cast inlay was assumed to be lower at 14 years.[7] Perhaps of more significance, is that several publications, including the present study, have reported either similar or better survivals for Class II amalgam restorations than for Class II cast restorations.[27-29]

CONCLUSIONS

Within the limitations of this cost-effectiveness study involving 245 large indirect restorations placed in 100 patients from three selected private dental practices, it was found that:

1. There were high median survival times found for most of the test and reference restorations. These times could not be calculated for the FGCs, CMCs and Class I amalgams, but exceeded 20 years. Therefore, the effectiveness of the treatments was based on restoration survival estimates at 5, 10, and 15 years.
2. At 15 years, the highest survivals were FGCs and CMCs, followed by PJCs, then the Class II cusp-overlay amalgams and Class IV multisurface resin composites. Cast onlays did not survive to 15 years.
3. When using cost discounting, the Class II cusp-overlay amalgam and the Class IV multisurface resin composite were found to be more cost-effective than any of the indirect restorations at all time intervals. The posterior FGC was more cost-effective than the CMC, and especially the cast onlay, at all time intervals. The anterior CMC was more cost effective than the PJC over the longer term.

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