Evaluation of the Cost-Effectiveness of Root Canal Treatment using Conventional Approaches versus Replacement with an Implant

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Abstract

Dental services consumed £1.6 billion of NHS expenditure in 2002, of which around 5% was spent directly on root canal treatment. Despite the level of expenditure, investigation of the cost-effectiveness of root canal treatment has not been extensively pursued. Recently, implant technology has provided an alternative to traditional orthograde (access through the crown) and retrograde (access through the gum) root treatment. While the initial cost of implant placement is high, implant supported restorations may be more durable than a root-filled tooth with significant decay, reducing maintenance costs.

This study evaluates ten principal treatment strategies for an upper front tooth with a root canal infection, which include interventions to preserve the endodontically infected tooth and to place a single implant supported restoration. Failure of all proposed interventions necessitates a bridge or denture to replace the tooth. A Markov model is used to predict the intervention costs of each treatment strategy over the lifetime of the patient. The primary outcome assessed is the duration of the tooth or implant supported crown prior to placement of a bridge or denture. All of the significant mechanical and biological complications arising after root treatment, implant installation or placement of a bridge or denture are modelled, to provide a comprehensive picture of the lifetime costs and outcomes of each treatment strategy.

Whilst no treatment (tooth replaced with bridge or denture) is the cheapest strategy, orthograde root treatment is cost-effective at very modest Willingness-to-pay values (£10-14 per year of delayed placement of the bridge or denture). Orthograde treatment and *re-treatment* is cost-effective at £21 per bridge/denture year avoided. Retrograde root treatment is never cost-effective. Immediate implant placement is very unlikely to be cost-effective, but provision of a single implant restoration after failure of orthograde treatment and *re-treatment* is cost-effective at £47-101 (male age 35 to 65) per bridge/denture year avoided.

Introduction

Dental services consumed £1.6 billion of NHS expenditure in 2003, of which around 5% was spent directly on root canal treatment [1]. Despite the considerable use of resources, cost-effectiveness analysis has not been extensively applied to dental practice. Dental diseases and interventions are rarely life threatening, and funding for large-scale trials is not readily available. Typical trials number less than 150 patients, and are often underpowered to detect significant differences between treatment techniques. Consequently, interventions to arrest tooth loss, especially root canal treatments, have developed in an ad hoc manner [2]. Evaluation has not kept pace with the advance in instrumentation leading to considerable debate over the efficacy of traditional versus surgical root canal treatments.

The traditional approach has been challenged by the rapid development of dental implants as an alternative technique for replacing natural dentition. Initially developed as an alternative to dentures for edentulous patients, the technology has been applied to support bridges and partial dentures, and as a support for single tooth replacement. While long term studies (greater than ten years) are scarce, the literature indicates excellent survival rates for implants [3]. A number of authors have suggested that implants offer a more predictable support for an artificial crown than a badly compromised natural tooth [4, 5].

This paper examines the cost-effectiveness of ten treatment strategies for an upper front tooth with an infected root requiring a post and crown. The principal interventions considered are orthograde and retrograde root canal treatments, a single implant supported restoration and replacement of the tooth with a bridge or partial denture. The consequences of each treatment strategy (series of interventions) are modelled over the patient’s lifetime, to attempt to quantify the full difference in costs and outcomes for each strategy. The main outcome considered is the lifetime of the original tooth or implant supported crown; whilst bridges may function adequately to replace natural dentition most patients are keen to avoid losing a tooth.

Overview of Interventions for Failing Teeth

Traditional dentistry has aimed to maintain natural dentition, wherever possible, as superior to the use of bridges and dentures to replace teeth. Badly compromised teeth with significant carious lesions are typically capped with an artificial crown to retain function and improve aesthetics. Decay that has reached the tooth root requires a root canal treatment (RoCT) where the nerve and blood supply inside the root (the pulp) is excavated and replaced with an artificial filling. Typically a post is inserted in the root to support an artificial crown where much of the natural crown has been lost. The prognosis of these teeth is dependent on the skill of the endodontist, but complications, some fatal for the tooth, are frequent.

Access to the root canal is normally created by boring through the crown (orthograde RoCT). The complexity of the procedure is influenced by the number and morphology of the roots. Curved roots and roots with branching channels clearly present a challenge in ensuring that all infected pulp matter is removed. *Re-treatment* of a root canal filled tooth with a recurring endodontic abscess requires removal of the original root filling and post. An alternative approach is surgery through the gum (retrograde RoCT) to seal the infection within the root. Success rates for surgery alone are modest [6], however recent publications suggest that surgery combined with orthograde re-treatment can achieve success rates of up to 90% [7].

Traditional bridges (Fixed Partial Dentures - FPDs) are anchored by a crown at one or both ends. However, crown preparation involves removal of a significant amount of natural enamel and dentine, and leaves the tooth at elevated risk of fracture and further decay [8]. Alternatives to FPDs exist. A removable partial denture (RPD) requires far less invasive preparation of adjacent teeth, but supporting clasps can harbour bacteria leading to increased carious attack, and irritate the gums causing inflammation [9]. The use of resin-bonded bridges (RBBs) can provide the stability of a fixed prosthesis with minimal destruction of neighbouring teeth. The bridge is cemented to adjacent teeth using a metal support, and is prone to debonding.

The use of artificial implants to support prosthodontics was regarded with scepticism until the pioneering work of Branemark [10], who showed that titanium implants could provide a stable, predictable support for dentures. A titanium cylinder is placed in the jaw bone below the gum and fuses with the bone over a period of 3-6 months. The cylinder head is re-exposed, allowing attachment of a crown via an abutment screwed to the implant. Osseo-integration failure rates are linked to the quality of the bone but are typically less than 2% [11]. Implant loss is rare after successful osseo-integration, provided good oral hygiene is maintained [12]. The main threat is Peri-implantitis [13], an infection of the gums around the implant which has a similar aetiology to Periodontitis [14]. Unchecked, the infection leads to accelerated bone resorption around the implant and eventual loss of the implant.

Economic Evaluation of Single Implant Restorations (SIRs)

While the ubiquitous QALY has not been applied to dental outcomes, a number of instruments for measuring Oral Health Quality of Life (OHQoL) are available. Validated instruments include the Geriatric Oral Health Assessment Index [15], the Dental Impact Profile [16], and the Subjective Oral Health Status Indicators [17], although the Oral Health Impact Profile (OHIP) [18] is the most widely used. A comparison of implant-supported and resin bonded fixed prostheses for patients with a gap of one or two teeth [19], using a quality of life measure adapted from the OHIP, reported no significant difference between the two groups in all the domains of the instrument, and that overall levels of OHQoL were high. A similar study [20] comparing implant supported FPDs and removable partial dentures found significantly lower OHQoL scores in patients receiving RPDs. While the data is limited, it suggests that fixed prostheses perform nearly as well as natural dentition in terms of OHQoL; removable dentures are less effective.

Studies of SIRs are scarce. Moiseiwitsch and Caplan [21] compared the cost of a RoCT with crown and post, and an implant supported crown. They report that the RoCT option is 37% cheaper, entails fewer consultations and is completed significantly quicker. They suggest that the prognosis for the restored root should dictate treatment. Bragger et al. [22] studied treatment costs over four years for two groups of patients receiving either an FPD or a SIR to replace a missing tooth. Laboratory costs for the FPD were about three times those of the single implant, and the resulting total costs for the SIR option were less.

In 2004 an NHS working group published a report on the cost-effectiveness of implant use in Scotland [23]. The authors conclude that placement of implants on the NHS should be restricted to cases of demonstrated need, namely restoration following jaw resection for oral cancer, severe trauma and where atrophy of the jaw bone prevents ordinary denture use. The lack of evidence of effectiveness, and the need for appropriately designed randomised controlled trials over longer time periods, has restricted the conclusions of reviews on implant use [24, 25].

Methods

The present study attempts to model the overall costs of various treatment strategies for a failing upper front tooth with inflammation of the root, where extensive decay necessitates a post supported crown. From a health care provider perspective the full cost of any treatment strategy should include the cost of future related health care costs, particularly where initial treatment can fail, requiring re-intervention. Therefore, the outcomes of ten treatment strategies (sequences of treatments) are modelled over the lifetime of the patient to assess the full costs of each treatment strategy. The interventions considered are orthograde root canal treatment, orthograde re-treatment, retrograde (surgical) re-treatment and placement of a single implant restoration. The model considers three options for replacing a failed tooth or implant, namely resin bonded bridges (RBBs), fixed partial dentures (FPDs) and removable partial dentures (RPDs).

Estimation of the OHQoL of patients in each of the model states is beyond the scope of this study. Effectiveness is judged primarily from the longevity of the single tooth restoration (root canal and crown, or implant) prior to placement of a bridge or denture. The model implicitly assumes that patients will retain most of their dentition over their lifetime, with artificial prostheses limited to partial bridges and dentures. Clearly some will not. However, levels of edentulousness are in retreat throughout the developed world, and provided good oral hygiene and appropriate care is maintained most people can be confident of avoiding dentures [26]. A further outcome measure, the number of visits requiring a local anaesthetic, provides a measure of the invasiveness of the treatment strategies.

The study considers costs from the perspective of a third party payer, no attempt was made to include productivity costs. Whilst the majority of dental care is reimbursed by the NHS, provision in the private sector is increasing, and in tandem the market for insurance payment plans is growing. Around 15% of the population is registered under private practice, and this rises to 50% in the South and South-East. This study provides an estimate of the intervention costs incurred for the treatment of a failing maxillary anterior tooth which might inform reimbursement decisions by a third party payer in the public or private sector.

Assumptions

The literature consists predominantly of follow-up of patients treated in dental hospitals, or in specialist clinics in the case of implants. As such it clearly represents best practice, and there is evidence to suggest that these standards are not always maintained in general practice. In an examination of post retained crowns in general practice in the UK, Grieve and McAndrew [27] judged the majority unsatisfactory and nearly 10% had no root filling at all. Whilst some evidence exists of lower effectiveness rates for implants in general practice in the UK [28], this may be partly attributed to a ‘learning curve’ effect [29], and evidence from Scandinavia suggests that similar rates of effectiveness can be achieved outside specialist research centres [30].

Following the publication by Leempoel et al. [31] on the appropriate presentation of results on the longevity of restorations, reporting of survival curves for both teeth and restorations has increased. Unfortunately the reporting of complications is typically selective and opaque, with rates difficult to discern. Consequently, some of the complication rates used in the model are based on approximations using the method described by Weiger et al. [32], whereby the overall reported frequency of an event is divided by the average period of observation to estimate a periodic event rate.

Most studies span all teeth, and while results for anterior and posterior teeth may be subdivided, the size of the study (often less than 150 patients) gives little confidence in the relative differences reported according to tooth location. Consequently much of the data used in the model is not location specific. It’s quite probable that the duration of restorations on maxillary canines differ from those on maxillary incisors; the very different stresses that molars and incisors are exposed to are well documented [33, 34].

Our model assumes that reasonable levels of oral hygiene are maintained, since oral hygiene and lifestyle factors (particularly smoking) have a significant influence on the prognosis of each intervention [12].

Treatment Strategies

The ten strategies evaluated included all reasonable interventions for which appropriate data was available. The choice of bridge type or denture could also be modeled as a strategic decision. However examining the merits of FPDs, RBBs and RPDs was beyond the remit of this study, hence the choice of prosthesis was parameterised as a random variable reflecting trends in general practice.

Strategy 1 (no treatment) - the tooth is replaced with a bridge/denture.

Strategy 2 (One RoCT) - a conventional (orthograde) RoCT is performed, with the tooth replaced with a bridge/denture on failure of the RoCT.

Strategy 3 (Two RoCTs)- orthograde RoCT is followed with orthograde retreatment (2^{nd} RoCT) where necessary. If the endodontic abcess returns the tooth is replaced with a bridge/denture.

In strategy 4 (RoCT/Surg) a failed conventional RoCT is followed by a retrograde RoCT (surgery) prior to consideration of a bridge/denture.

In strategy 5 (RoCT/Implant) a failed RoCT precedes extraction of the tooth and placement of a SIR. Failure of the SIR requires a bridge/denture.

In strategy 6 (RoCT/Two implants) a failed RoCT precedes extraction of the tooth and placement of a SIR. A second implant is placed if the first is lost. Failure of this implant requires a bridge/denture.

Strategy 7 (Two RoCTs/Implant) allows two orthograde RoCT to save the tooth. If this fails the tooth is replaced with a SIR. Failure of the SIR requires a bridge/denture.

In strategy 8 (RoCT/Surg/Implant) an orthograde RoCT is followed by a surgical RoCT if unsuccessful. If this fails the tooth is replaced with a SIR. Failure of the SIR requires a bridge/denture.

In strategy 9 (One implant) RoCT is not used. The tooth is replaced with a SIR. If the implant fails a bridge or denture is fitted.

In strategy 10 (Two implants) the tooth is replaced with a SIR. A second implant is tried if the implant fails. A second failure requires intervention with a bridge/denture.

The Model

The study uses a Markov model built with TreeAge software [35]. The cycle length is six months. Half cycle correction was not used. Six months is the traditional period between dental check-ups, and reflects the typical osseo-integration period for an implant inserted using the standard two stage procedure[1], prior to fitting the crown. The osseo-integration period is represented as a Markov state. An initial state is also used to capture the increased likelihood of root perforation during the RoCT procedure. Hence each procedure on the failing tooth has an initial Markov state including intervention complications. After initial treatment the probability of all events is assumed to be constant.

The model contains thirteen distinct Markov states. There is a Markov state for the initial six months and one for the subsequent lifetime of the restoration following orthograde RoCT, orthograde re-treatment, surgical RoCT, first implant placement and second implant placement. In addition there is a Markov state representing FPDs, RBBs and RPDs. Each strategy is modelled using the appropriate root canal intervention and/or implant states, and the three bridge/denture states representing the options for bridging a small gap. Each strategy allows a number of interventions, either to treat an endodontically inflamed tooth or establish a SIR before resorting to bridgework; however tooth loss due to fracture or biological attack in the root canal states precludes further root treatment. The model considers all of the significant mechanical and biological events that would incur a treatment cost in order to evaluate the full cost of each of the treatment strategies.

Rates of complications in the various root canal treated tooth states, apart from a return of the root infection, are assumed to be independent of whether a re-treatment has occurred. In reality it's likely that re-excavating the tooth root will increase the probability of events such as root fracture. Incorporation of data to parameterise the probability of each possible event, and the overall failure probabilities would have over-specified the model. Consequently the probability of a re-occurrence of the root infection was chosen to ensure that the overall failure rates of root treated teeth matched appropriate literature values.

The same issue was confronted in parameterising the Bridge/Denture states. Here overall 'survival rates' were not used directly to parameterise the state; survival was the outcome of no fatal event occurring. In the implant states none of the mechanical complications were deemed fatal[2], allowing survival of the implant and mechanical complications to be parameterised independently. Although implant loss is typically caused by infection, probability of implant loss

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[1] Traditionally the implant is placed under the gum and left to fuse with the bone for 3-6 months prior to exposure and attachment of the abutment and crown. In the single stage procedure the abutment is connected immediately. The optimal approach has not yet been established.

[2] Fracture of the implant, a fatal mechanical failure, is extremely rare in SIRs, and Berglundh reports none in the studies he analyses, hence it was ignored.

and peri-implantitis were modelled independently on the basis of separate rates reported in the literature. The probability of peri-implantitis and loss of a second implant is increased by 30% after failure of the first implant, based on the report by Weyant and Burt [36].

As failures of abutment teeth, particularly in FPDs, are not infrequent, the model allows for abutment failure. Transition between one of the three bridge/denture states results, hence each state represents a small gap rather than a specific single tooth replacement prosthesis. Ideally the fate of the adjacent teeth and the interventions required should be modelled whether or not they are used as abutment teeth to support a prosthesis. In the interests of brevity this was not attempted. The failure of prostheses due to loss of abutment teeth is modelled, and the costs of interventions on the abutment teeth are adjusted to allow for procedures which may have been required in the absence of the prosthesis[3].

Data Sources

A search of the MEDLINE, EMBASE, DARE and the Cochrane Library databases was undertaken (from inception to Jun 2006) to recover all relevant papers on the survival and maintenance requirements of each tooth state in the model. The search was supplemented by checking the references of all papers retrieved for further relevant studies. In deciding the choice of parameters to enter into the model, a 'hierarchy of evidence' approach was used. Meta-analyses were utilised where available, otherwise parameters were chosen based on the size, quality, age and selection criteria of the study. In the rare instances where no appropriate data was available the expert opinion of Prof. Jimmy Steele and Dr John Whitworth was sought. All the parameters chosen were scrutinised by this panel to verify their appropriateness. It should be noted that as the model uses a six month cycle the failure probabilities are biannual.

Cost calculations are for interventions conducted in an NHS secondary care setting, namely the School of Dental Sciences, Newcastle University. The costing of the each procedure was undertaken by Chris Vernazza, using professional judgment to estimate time costs and resources. The base case analysis assumes that all implant procedues are carried out by a consultant dentist. All of the conventional dental procedures are costed using a Specialist Registrar or Senior House Officer rate apart from surgical re-treatment of a root canal, where a consultant was deemed appropriate. Staff costs are based on mid-band salaries. No figure was available for overhead costs, hence the overhead charge for insurance claims of £40/hour was used in the base case. Costs and outcomes are discounted at 3.5%. Overhead costs and discount rates were varied in the sensitivity analysis.

[3] The degree to which abutment teeth are subject to increased carious and periodontal disease is highly contentious. Whilst optimal oral hygiene and dental care will protect abutment teeth, the same might be said of any tooth! Studies in general practice show an increased risk for FPDs and RPDs.

Parameterising the Model

Root Canal Treatment

The data on RoCT is varied, and many studies are more than 30 years old but some consensus on outcomes is discernible. A study by Creugers et al. [37] selected only three papers for analysis and concluded that heterogeneity of the survival criteria precluded a meta-analysis. The study by Mentink et al. [38] was by far the largest of the three, and provided a survival curve for maxillary anterior cast post supported crowns, hence this report was prioritised when parameterising the RoCT state. The probability of a re-occurrence of an endodontic abscess was adjusted so that the overall failure probability, as classified in the Mentink paper, matched Mentink's reported value of 0.99%. The resulting value for a returning endodontic abscess (0.48%) is close to the value of 0.61% calculated from the data in the report by Bergman et al. [39]

All event probabilities except a returning endodontic abscess were assumed to be the same after *re-treatment* with a further orthograde or retrograde RoCT. Sjogren et al. [40] report the number of remaining teeth ten years after orthograde *re-treatment*, and this value was used to calculate a biannual failure rate of 2.62%. Using the method outlined above a biannual probability of a return of the endodontic abscess of 2.02% was calculated to parameterise the orthograde re-treated tooth state. Recent publications have suggested a higher success rate for surgical treatment performed alongside orthograde re-treatment [41, 42]. The base case uses success probabilities reported by Buhler [43] to calculate a biannual probability of a return of the endodontic abscess of 1.30% after retrograde RoCT (surgery), significantly lower than that calculated for orthograde re-treatment.

Single Implant Restorations

There are a considerable number of publications on implants in the literature including three meta-analyses of implant survival data [30, 44, 45]. The Berglundh meta-analysis [44] is the most recent, but its strict inclusion criteria result in a survey of a rather eclectic mix of implant systems. The Creugers meta-analysis [45] fails to distinguish between implants that failed to osseo-integrate and those lost during function. Consequently, failure probabilities for implants pre and post loading used in the model are taken from the Lindh meta-analysis [30], although it is limited to Branemark implants. Whilst Branemark remains one of the leading firms several other manufacturers' systems are commonly used[4]. Reports from Esposito et al. [46, 47] found no significant difference in the failure rate for six commonly used systems, but few direct comparisons have been undertaken [48-51]. The Berglundh meta-analysis also provided data on biological and technical complications.

[4] There are as many as 300 different types of implants on the market! Other common manufacturers include Nobel Biocare, ITI, IMZ, Implant Innovations, Astra, and Straumann.

Bridge/Denture States

Reports on the durability of FPDs cite a diverse range of complications in overlapping categories. Three meta-analyses were available [52-54] of which the report by Tan et al. [54] is the most recent and comprehensive, and was used where possible. The meta-analysis by Scurria et al. [53] includes a survival curve for abutment teeth. FPDs require significant removal of the natural crown of the abutment teeth, and the degree to which this shortens the lifespan of these teeth is debated [8, 55, 56]. Bergenholtz et al. [57] report the incidence of caries, periodontal and endodontal disease in abutment and non-abutment teeth, and these findings were used to calculate the proportion of abutment tooth loss that was directly attributable to the FPD. The biannual probability of loss of an abutment tooth predicted by the model (0.36%) is consistent with the figure calculated from the survival curve presented by Scurria et al. [53] (0.20%; per tooth, each bridge has two!). The overall failure probability for FPDs (0.63%) and the probability of any intervention (1.75%) are close to the results reported in the Tan meta-analysis (0.58% and 1.63% respectively)[5].

There are few reports on the longevity of resin-bonded bridges, and sadly the meta-analysis by Creugers et al. [58] is ambiguous[6]. A study by Creugers et al. [59] provides an explicit breakdown of failure rates for RBBs, and this paper provided most of the data for the RBB state. It was assumed that the rates of periodontal, endodontal and carious events in abutment teeth were not influenced by the presence of the RBB, hence the rate of abutment loss due to these factors was modelled purely to estimate the impact on costs of prosthesis replacement.

Data on the longevity and complication rates for RPDs is minimal. It is generally accepted that RPDs subject abutment teeth to increased carious attack, and Chandler and Brudvik [60] report the rate of caries incidence in abutment and non-abutment teeth. As with the FPD state this allowed an estimation of the proportion of abutment losses due to caries which would have occurred in the absence of the denture, and an appropriate adjustment to the cost of treating these caries was made. Incidence of periodontal and endodontal disease was assumed to be unaffected by the RPD.

The choice of prosthesis after loss of a tooth/implant, or loss of an abutment tooth from a bridge or denture was parameterised using expert opinion provided by Jimmy Steele, as the two studies available [61, 62] were considered out of date. The parameters selected and appropriate references are shown in Table 1 below.

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[5] The yearly incidence rates reported in the Tan meta-analysis have been converted to biannual rates.

[6] The paper appears to be referring to 'survival' as an intact bridge that hasn't debonded, but no explicit failure definition is given.

Parameter	Value	Source	Parameter	Value	Source
Adjustment to costs for caries (FPD)	0.75	[57]	p. of perio. disease around FPD/RPD abut.	0.00183	[69]
Adjustment to costs for caries (RPD)	0.55	[60]	p. of periodontal disease around RBB abut.	0.00183	[69]
Adjustment to costs for endo. abcess (FPD)	0.9	[57]	p. of periodontal disease in root filled tooth	0.0026	[39]
Adjustment to costs for perio. disease (FPD)	0.5	[57]	p. of success. treating perio. in RBB abut.	0.77	[57, 69]
Cost of abut. screw fracture (Implant)	84.16	C.V.	p. success. treating perio. in FPD/RPD abut.	0.863	[54, 69]
Cost of tooth extraction (all states)	129.44	C.V.	p. success. treating perio. in root filled tooth	0.4923	[39, 70]
Cost of caries treatment (filling, all states)	105.42	C.V.	p. of endo. abcess 1st root treatment	0.00482	#
Cost of recementing crown (tooth/implant)	50.32	C.V.	p. of endo. abcess 2nd root treatment	0.0202	#
Cost of repairing crown (tooth, bridge states)	105.42	C.V.	p. of endo. abcess after surgery	0.013	#
Cost of placing crown on implant	969.47	C.V.	p. of endo. abcess in RBB/RPD abut. tooth	0.00193	[57]
Cost of making/installing a 3-unit FPD	788.83	C.V.	p. of treatable endo. abcess in FPD abutment	0.00155	[71]
Cost of making/installing a 4-unit FPD	936.04	C.V.	p. of fatal endo. abcess in FPD abut. tooth	0.00101	[72]
Cost of repairing fractured RPD	104.09	C.V.	p. succ. treat. endo. abcess RBB/RPD abut.	0.6	*
Cost of treating periodontal disease	175.53	C.V.	p. of root damage 1st root treatment	0.003	[38]
Cost of placing implant in gum	677.56	C.V.	p. of root damage 2nd root treatment	0.0036	[38, 73]
Cost of recementing post (RoCT states)	50.32	C.V.	p. of caries in FPD abutment tooth	0.00497	[54]
Cost of making/installing a 3-unit RBB	407.25	C.V.	p. of caries in RBB abut. tooth	0.00197	[59]
Cost of making/installing a 4-unit RBB	457.25	C.V.	p. of caries in root filled tooth	0.00127	[39]
Cost to reattach one or both wings (RBB)	57.95	C.V.	p. of caries in RPD abut. tooth	0.01065	[60]
Cost to repair fractured crown on implant	125.42	C.V.	p. of failing to treat caries in RBB abut. tooth	0.2132	[57,59]
Cost to replace crown on implant	672.74	C.V.	p. of success. treating caries in FPD abut.	0.736	[54]
Cost to replace crown on post	444.57	C.V.	p. success. treat. caries filled tooth/RPD abut.	0.685	[39]
Cost - orthograde root treat. post and crown	671.74	C.V.	p. of non-repairable crown fracture on implant	0.0033	[74]
Cost - orthograde re-treatment post and crown	690.3	C.V.	p. of crown fracture on post	0.00215	[70]
Cost of root canal treatment without crown	358.53	C.V.	p. of repairable crown fracture on implant	0.0008	[64]
Cost of making/installing a 3-unit RPD	479.07	C.V.	p. of repairing crown fracture on post	0.195	[70]
Cost of tooth addition to RPD	186.01	C.V.	p. of crown loosening on implant	0.0033	[75]
Cost of RPD reline	109.09	C.V.	p. of crown loosening on post	0.00534	[70]
Cost of surgical re-treatment post and crown	1114	C.V.	p. of post loosening	0.00876	[38]
Cost of treating peri-implantitis	190.68	C.V.	p. of fractured post	0.00237	[38]
Cost of treating implant loss	93.52	C.V.	p. of successfully repairing loose post	0.923	[76]
p. of abutment tooth fracture (FPD)	0.00106	[54]	p. of successfully repairing fractured post	0.833	[76]
p. of abutment tooth fracture (RPD)	0.313	[63]	p. of implant graft failure	0.011	[30]
p. of tooth fracture after root treatment	0.00335	[38]	p. of peri-implantitis	0.0016	[44]
p. of abutment screw fracture (implant)	0.0023	[64]	p. of implant loss	0.00237	[30]
p. of aesthetic failure (FPD, RPD)	0.00135	[65]	Multiplier - increased prob. of 2nd implant fail	1.3	[36]
p. of aesthetic failure (RBB)	0.00135	[65]	p. of FPD fracture	0.00042	[65]
p. of aesthetic failure (RoCT/Implant)	0.0183	[66]	p. of FPD working loose	0.0033	[54]
p. of fitting bridge after fatal failure of RBB	0.5	*	p. of repairing fractured FPD	0.18	[67]
p. of fitting bridge after abut. loss in RBB	0.8	*	p. of repairing a loose FPD	0.818	[54, 72]
p. of fitting bridge after tooth or implant loss	0.8	*	p. of porcelain fracture in FPD	0.0021	[65]
p. of fiiting bridge after FPD fracture	0.79	[67]	p. of both wings debonding (RBB)	0.01533	[59]
p. bridge fitted after implant/tooth loss is FPD	0.4	*	p. of one wing debonding (RBB)	0.02117	[59]
p. of fitting FPD after an abut. loss with FPD	0.7	*	p. of fatal pontic fracture on RBB	0.00148	[59]
p. of fitting RBB after abut. loss from FPD	0	*	p. of repairable pontic fracture on RBB	0.02069	[59]
p. of fitting FPD after an abut. loss with RPD	0.1	*	p. of RBB framework failure	0.00689	[59]
p. of fitting RBB after abut. loss from RPD	0	*	p. of RPD base fracture	0.00815	[77]
p. of RBB to replace bridge after RBB failure	0.7381	[68]	p. of RPD requiring reline	0.01604	[60]

*expert opinion # calculated from overall failure rates C.V. – source Chris Vernazza

Table 1. Model parameters

Results

Table 2 below presents the lifetime costs for each treatment strategy alongside the longevity of the tooth or implant supported crown prior to placement of a bridge or denture. The third column (Locals) gives the expected number of procedures requiring a local anaesthetic pertinent to the tooth in question over the patient’s lifetime. The cheapest strategy is always strategy 1 (no treatment), followed by strategy 2 (one RoCT) and then strategy 3 (Two RoCTs). Whilst surgical re-treatment of the tooth is more effective in eliminating the endodontic abscess compared to orthograde re-treatment, the increased cost of the procedure is not recouped by extending the life of the tooth. Strategies 9 and 10 are significantly more expensive than the other strategies due to the high initial costs of implant placement. The relative difference is larger than the findings of Moiseiwitsch and Caplan [21] (implants 37% more expensive than conventional RoCT), despite the authors examining only initial costs.

	male age 35			male age 55			male age 75		
Strategy	Cost	Longev.	Locals	Cost	Longev.	Locals	Cost	Longev.	Locals
1 (No Treatment)	£819	0	1.85	£731	0	1.7	£613	0	1.5
2 (One RoCT)	£971	15.81	1.86	£875	12.62	1.58	£744	7.1	1.27
3 (Two RoCTs)	£1,003	17.29	1.83	£895	13.56	1.55	£751	7.41	1.25
4 (RoCT/Surg)	£1,063	17.51	1.78	£943	13.66	1.53	£779	7.43	1.24
7 (Two RoCTs/Implant)	£1,205	21.62	2.19	£1,057	15.79	1.83	£840	8	1.4
8 (RoCT/Surg/Implant)	£1,284	21.62	2.19	£1,116	15.79	1.83	£871	8	1.39
5 (One RoCT/Implant)	£1,319	21.47	2.29	£1,157	15.73	1.96	£900	7.99	1.5
6 (RoCT/Two implants)	£1,329	21.43	2.55	£1,163	15.72	2.1	£902	7.99	1.53
9 (One Implant)	£1,830	20.12	2.23	£1,770	14.96	2.16	£1,676	7.74	2.05
10 (Two Implants)	£1,936	21.73	2.38	£1,851	15.83	2.28	£1,721	8.01	2.12

Table 2. Base case results – cost, number of local anaesthetics and average time spent in tooth or implant states

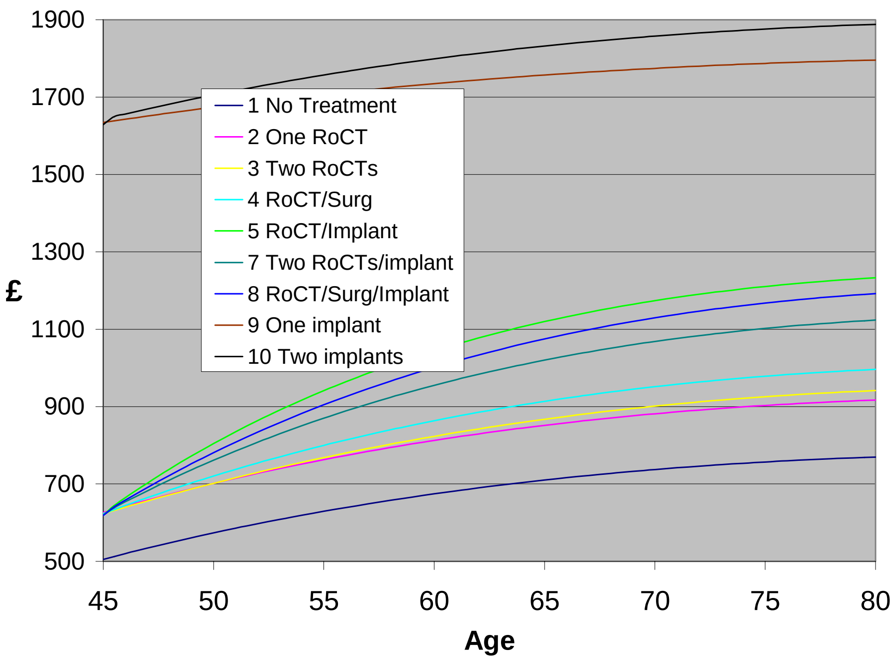

Figure 1. Cumulative Costs of each strategy (male age 35)

The model predicts superior survival of the SIR over a conventional root canal treated tooth supporting the view of Priest [8] and Mayer [5]. After twenty years around 25% of root treated and *re-treated* teeth have been lost, whereas 10% of implants have failed, necessitating a further implant or bridge/denture. Despite improved longevity the implant states require more invasive procedures. This is due to the two stage procedure for implant installation and abutment connection modelled here, requiring two local anaesthetics. Figure 1 above shows the cost accumulation for each strategy[7] over 35 years for a male age 45. The significantly greater initial outlay on placing an implant is partly recouped in lower ongoing costs. The ongoing costs of strategy 5 (RoCT/Implant) show the steepest gradient, due to a combination of high failure rates of the conventional first treatment (RoCT), and the high cost of the second treatment (implant).

Cost-effectiveness Analysis

A cost-effectiveness analysis was performed examining the duration of the tooth or implant restoration against the cost. The results are shown in table 3 below. The ICER shows the incremental cost of the additional bridge/denture years avoided. All strategies including surgery were extendedly dominated. Whilst surgery is more effective than orthograde RoCT in re-treating the root infection, a much better outcome is achieved by replacement with an implant making these strategies more cost-effective. Evidently strategy 10 (two implants) whilst most effective is not cost-effective, but strategy 7 (two RoCTs/Implant) is cost-effective if the payer values a year without a bridge or denture at £50 - £100 (male age 35-65).

	ICERs for male age 35 to 85					
Strategy	35	45	55	65	75	85
2 (One RoCT)	£10	£10	£11	£14	£19	**ED**
3 (Two RoCTs)	£21	£21	£21	£21	£21	£29
7 (Two RoCTs/Implant)	£47	£57	£73	£101	£151	£244
10 (Two Implants)	£6,735	£10,756	£20,364	£48,602	£157,710	£751,913

Table 3. Base case cost-effectiveness analysis

Effects of Cheaper Implants

	male age 35		male age 45		male age 55		male age 75	
Strategy	Cost	ICER	Cost	ICER	Cost	ICER	Cost	ICER
1 (No Treatment)	£819		£781		£731		£613	
2 (One RoCT)	£971	£10	£929	£10	£875	£11	£744	£19
3 (Two RoCTs)	£1,003	**ED**	£955	£21	£895	£21	£751	£21
7 (Two RoCTs/Implant)	£1,090	£20	£1,082	£25	£970	£34	£796	£76
10 (Two Implants)	£1,355	£2,449	£1,570	£4,120	£1,293	£8,298	£1,200	£72,371

Table 4. Cost-effectiveness with cheaper implant components and wage rates

General diffusion of implant technology is likely to lead to lower component costs and a familiarisation of general dentists with implant techniques. This was

[7] Strategy 6 (RoCT/two implants) has been excluded for clarity but follows essentially the same trajectory as Strategy 5 (RoCT/Implant).

modelled by halving all the implant component costs, and recosting procedures at specialist registrar rates (£25.93/hour) rather than consultant rates (£56.23/hour). All other costs - medicaments, consumables, labwork for prostheses etc. were kept the same. Strategy costs and ICERs for non-dominated strategies are displayed in table 4. The effect on strategy 7 (two RoCTs/Implant) is marked, it now extendedly dominates the conventional re-treatment option for a young patient.

Sensitivity Analysis

The degree of coronal destruction and the size of the root inflammation will clearly affect the prognosis of the tooth. Linde [78] presents data on a study of the longevity of root treated teeth which were extensively decayed, necessitating a threaded post to retain the crown. Applying event rates calculated from this paper increases costs for strategies requiring RoCT by ca. 10%, and the longevity of the root filled tooth is reduced by ca. 10%. The overall strategy rankings are unchanged but ICERs are increased (for a male age 45 strategy 2 (one RoCT) increases to £19, and strategy 3 (Two RoCTs) increases to £30).

Model parameters with a significant individual effect on overall strategy costs were identified using a tornado analysis. The effect on each strategy cost of varying each transition probability in isolation over a range of roughly half to double its original value was calculated. For the parameters with the biggest influence on strategy costs, expert opinion on the veracity of the parameter estimate and a likely range was sought. One-way sensitivity analysis of the model results with each of the parameter ranges was then performed. In each case the impact on the overall cost-effectiveness of each strategy was small, and no changes in the overall rankings were observed.

The cost data available was considered far more reliable than the transition parameters hence no sensitivity analysis was performed. The exception to this was the overhead costs, which formed a significant portion of the cost of most procedures. A sensitivity analysis was performed with overhead costs set at £25 and £65. Unsurprisingly costs were affected, but the changes in ICERs were small and there was no effect on the overall strategy rankings. Varying the cost discount rate and the benefit discount rate over a range of 0-7% has a significant impact on ICERs, but the overall ranking of the strategies is unchanged. Table 5 illustrates the impact on ICERs for a male age 45.

benefit discount rate cost discount rate	3.50% 0%	3.50% 3.50%	3.50% 7%	0% 3.50%	3.50% 3.50%	7% 3.50%
2 (One RoCT)	£12	£10	£10	£6	£10	£14
3 (Two RoCTs)	£44	£21	£12	£11	£21	£37
7 (Two RoCTs/Implant)	£70	£57	£49	£34	£57	£92
10 (Two implants)	£9,260	£10,756	£11,483	£3,736	£10,756	£25,603

Table 5. Effects of varying the discount rate for costs and benefits

Discussion

While strategy 1 (no treatment) is the cheapest treatment strategy, standard root canal treatment is cost-effective if the patient/payer values retention of the tooth at more than £10 - £20 per year. Orthograde re-treatment (strategy 2) becomes cost-effective if the patient/payer values a year of the tooth at more than £21. After twenty years 35% of conventional root treatments have failed in that the tooth has undergone re-treatment or extraction. Surgical re-treatment offers a marginally better prognosis for the lifetime of the tooth, but strategies including this intervention are always extendedly dominated by strategies where a SIR is used, hence surgery is not cost-effective. Whilst immediate placement of implants is not cost-effective, placement of a SIR if RoCT and orthograde re-treatment fails (strategy 7), is cost-effective if the patient/payer values a year of the tooth/implant restoration at £47 - £101 or more (male age 35 –65).

The value of a Bridge/denture year avoided is difficult to quantify. The OHQoL evaluation performed by Sonoyama et al. [19] suggests there is little difference in patient outcomes for a 3-unit bridge compared to a SIR. However, there is little doubt that FPDs and RPDs accelerate the loss of abutment teeth through increased risk of caries, endodontic infection or both [8]. RBBs appear to offer a significant improvement in prognosis for abutment teeth, but long term studies are limited. Nevertheless it seems reasonable to postulate that instalment of a bridge or denture commences a cascade of events that shorten the lifetime of adjacent teeth. In the case of crowned teeth this effect has been described as 'the molar life cycle' [79]. Many patients are keen to avoid a requirement for a bridge or denture.

Clearly some measure of the value of a natural root or implant supported crown is needed. Whilst the Quality Adjusted Tooth Year (QATY) described by Birch [80] might provide a basis for an outcome measurement, it is a long way from being sufficient. The value of a tooth is a function of its location, condition, aesthetic contribution and the condition and location of the complementary dentition. In addition, retention of a tooth may have a positive influence on the lifetime of adjacent and opposing teeth [81] which should be evaluated. In principle all these factors could be captured with Healthy Year Equivalents [82], but the valuation process would be extremely complex. A generic system for valuing tooth states would be invaluable for evaluating dental treatment strategies.

Equally some measure of the 'unpleasantness' of dental visits is needed. In this study a decision was taken to count the number of procedures requiring a local anaesthetic as a measure of this outcome. Few people welcome a dental procedure requiring a local anaesthetic, and phobic responses in some may deter adherence to regular check-ups. Determination of the Willingness to Pay to avoid a local anaesthetic might be an appropriate way to value this outcome.

The use of consultant rates to cost of all the implant procedures reflects a consideration of implant technology as ‘specialist’. However, implant procedures are becoming increasingly routine. The model suggests that as the technology embeds, offering a SIR after the failure of orthograde re-treatment will be cost-effective at fairly modest WTP values to avoid a bridge or denture.

Limitations of the Study

Two principle simplifications were made when building the model. Firstly a constant hazard rate was assumed for mechanical and biological complications following an intervention. This was a pragmatic decision to keep the model simple, but for most parameters appropriate life tables are not available. Whilst this clearly does not represent the natural history of endodontic disease after root canal treatment, it is hoped that a reasonable approximation of the attrition rate of root canal treated teeth has been achieved. The hazard rates for bridge maintenance are evidently not constant, with an acceleration of many failure events after ten years [52]. Failures of implants appear to occur more frequently in the early years beyond which a plateau is often observed in reported studies. Nonetheless a small annual retreat of the jawbone around implants (0.1 mm per year) has led some researchers to postulate a bimodal survival curve, with failure rates increasing over longer periods [12].

A major simplification of the biological complications of implants was made for the implant state, where a small annual incidence of either peri-implantitis or outright implant loss is modelled. In reality the most likely cause of implant loss after osseo-integration is the unchecked progress of peri-implant infections [13]. The risk of implant loss, and treatment costs are clearly dependant on the degree of implant infection. A series of implant states to model the progress of infection levels would have improved the model, but the data to support this wasn’t available.

Conclusions

The present study supports a role for root canal treatment in the management of endodontic disease. Root canals requiring a post and core are expensive (ca. £580), but cost-effective at very modest values of Willingness to pay to maintain the original tooth (£10–19 per year). The case for orthograde re-treatment is strengthened, it’s cost-effective at fairly modest WTP values to retain the tooth (£21 per year). The survival curves for root treated teeth and implants support the views of Priest [8] and Ruskin [4] that implants provide a more predictable platform for an artificial crown than a root filled tooth with a post. However, if the ultimate goal is to delay the onset of a bridge or denture then orthograde root treatment will greatly extend the life of a tooth before exploring implant options. Despite the improved prognosis with modern surgical techniques surgical re-treatment is not a cost-effective strategy.

The availability of data on the longevity of tooth restorations is remarkably scant. Given the annual cost of root treatments in the UK alone, the failure of the literature to yield appropriate data for a meta-analysis of the survival of root treated teeth exposes a fundamental knowledge gap which ought to have been addressed a long time ago. Data on the longevity and effects of RPD use is miniscule despite evidence that they accelerate the loss of adjacent teeth. Cost-effectiveness analysis of dental expenditure becomes a more subjective exercise without high quality studies of the outcomes of treatments. This study has relied upon clinical data which may not reflect the effectiveness of dental procedures in wider practice.

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