Evaluating the Health Economic Implications and Cost-Effectiveness of Dental Implants: A Literature Review

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Purpose: *To review the available literature on the costs and cost-effectiveness of dental implant-supported or -retained prostheses versus tooth-supported fixed partial denture restorations or mucosa-borne conventional complete or partial dentures.* ***Materials and Methods:*** *A systematic literature review of the PubMed, EMBASE, and Cochrane Library databases was conducted, restricted to studies published in English between November 2000 and November 2010. The searches returned a total of 381 unique hits, and a total of 14 studies on the long-term costs or cost-effectiveness of dental implants were included in the final review. A true systemic review was complicated by the heterogeneity of the conducted studies.* ***Results:*** *For single-tooth replacement, dental implants were generally either cost saving or cost-effective in comparison with tooth replacement using traditional fixed dental prostheses. For patients with mandibular edentulism, dental implants were associated with higher initial costs in comparison with conventional mucosa-borne dentures. However, the consensus among most studies was that, over the long term, dental implants represent a cost-effective treatment option. Additionally, patient acceptance, satisfaction, and willingness to pay for dental implants were high, particularly in elderly edentulous patients. A trend toward improved overall health and decreased health care costs was also reported.* ***Conclusions:*** *For single-tooth replacement, a single implant was a cost-effective treatment option in comparison with a traditional three-unit fixed dental prosthesis. For the replacement of multiple teeth, dental implants (fixed or removable prostheses) were associated with higher initial costs but better improvements in oral health–related quality of life compared with other treatment options.* Int J Oral Maxillofac Implants 2013;28:343–356. doi: 10.11607/jomi.2921

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In recent years, improvements in oral health have resulted in a decline in the prevalence of edentulism in both North America and a number of European countries. For example, in the United Kingdom alone, the prevalence of edentulism declined from 79% in 1968 to 57% in 1988.[1–3] Despite such improvements, estimates from 2007 indicate that approximately 50% of European adults wear some form of prosthetic dental restoration.[4] Prosthetic restorations, such as fixed dental prostheses, are frequently indicated for the replacement of missing teeth, the restoration of severely damaged teeth, as well as for esthetic purposes. The use of dental implants represents an alternative to traditional tooth-supported prostheses, and some studies have suggested that dental implants are associated with improved clinical outcomes, which has resulted in their increased usage, with up to 4% of the adult population possessing dental implants in some settings.[4]

The use of dental implants has a number of key advantages in comparison with conventional fixed restorations and partial and complete removable dentures. In edentulous patients, the use of dental implants has been shown to lead to improved masticatory function, decreased bone resorption, less prosthesis mobility, and improved oral health–related quality of life (OHRQoL) in comparison with conventional dentures.[5,6] In particular, the diminished retention and stability of mandibular conventional dentures is a common problem among conventional denture wearers and is evidenced by the widespread use of dental adhesives.[7] Furthermore, prosthetic movement may result in a considerable proportion of patients altering their diets to avoid foods that they find especially problematic, which may, in turn, lead to nutritional deficits in some patients as well as avoidance of certain social interactions and recurrent mucosal irritation.[8,9] For example, in a study comparing

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nutrient intake in patients with conventional dentures versus those with implant overdentures, there were significant differences between the groups in terms of ease of eating beef; chicken; hard raw vegetables and fruits; fruit with peel; crusted breads; nuts; and seeds.[10] Indeed, the evidence for the improved outcomes associated with the use of implants was deemed compelling enough that the 2002 McGill Consensus Statement on Overdentures recommends the use of two-implant overdentures as the first choice treatment for patients with an edentulous mandible.[11]

Despite the fact that the placement of implants is a surgical procedure, evidence from some studies suggests that the acceptance of dental implants among the general public seems to be high, and the placement of implants has become increasingly common in recent years as the use of implant dentistry has become more widespread. Indeed, in the United States, the number of dental implants placed over the period 1986 to 1990 increased by 275%.[3] However, the perceived high cost of dental implants by both patients and dentists remains a notable barrier to their use in many instances. For example, in an early analysis of costs, MacEntee and Walton reported that the cost of a removable implant prosthesis (2 implants) was 7 times that of a conventional denture, and that the cost of a fixed implant prosthesis (5 implants) was 17 times that of conventional dentures in Canada.[3] However, since these early publications, there have been advances that have led to substantial decreases in the chairtime required and in component costs of implant-based treatment. For example, the introduction of computer-aided design/computer-assisted manufacturing (CAD/CAM) technology to replace conventional fabricated custom abutments in fixed restorations and decreased use of overdenture bar constructions has resulted in lower overhead costs in more recent years. Technologic advances have led to improvements in already high success rates, with 5-year success rates with implant-supported overdentures of up to 99% in some practices.[12]

A notable benefit associated with the use of dental implants for single-tooth replacement is that their use generally does not compromise the condition of the neighboring teeth.[13,14] However, studies have shown that gingival recession and bone loss may occur in the area surrounding the implant in some patients.[15] Additionally, bone resorption commences once teeth have been extracted and implant placement has been associated with less bone loss in the edentulous area in comparison with tooth-supported dental prostheses. Moreover, missing teeth represent an important esthetic consideration for many, and in a recent survey conducted in Austria, Tepper et al reported that 97% of respondents thought that missing teeth should be replaced in adults.[16] Interestingly, the authors also reported that the acceptance of dental implants to replace missing teeth varied considerably according to age and was highest in those under 30 years of age, where 75% of respondents were willing to accept dental implants if needed. Another noteworthy finding of that study was that although knowledge of the actual cost of implants was low, the perceived high cost was a considerable barrier, with 79% of respondents stating that they thought that the cost of dental implants was too high.[16] However, knowledge of the costs associated with dental implants and willingness to pay may be dependent on a number of factors, including whether patients are partially or completely edentulous and the degree of satisfaction with conventional dentures. However, despite high levels of acceptance, Gatten et al showed that patients preferred treatment options that would allow for preservation of the natural dentition when possible.[17] Willingness to pay was examined in a Canadian study of completely edentulous elderly individuals with first-hand experience with conventional dentures or dental implants; 70% of those with implants were willing to pay three times the cost of conventional dentures for implants, rising to 96% of implant wearers if payment by installment was an available option.[18]

Although early studies suggested that the initial treatment costs associated with dental implants are typically greater than those with other prosthetic dentistry options, patient satisfaction and improvements in OHRQoL are also typically greater in patients with dental implants. However, more recent data have suggested that, for single-tooth replacement over the long term (20 years), dental implants were projected to be associated with lower overall costs and higher success rates in comparison with tooth-supported dental prostheses.[19] Additionally, survival rates are high for implant-based prostheses. Studies on fixed prostheses have shown 5-year survival rates of 96.5% for single-tooth replacement and 95.4% for implant-supported fixed prostheses.[20,21] The suggestion that dental implants are associated with higher costs but at the same time improved outcomes in comparison with other treatment options raises questions relating to the cost-effectiveness of dental implants in comparison with other treatment options, especially when crown lengthening, endodontic therapy, and post-core buildup become necessary to restore a compromised tooth. However, in dentistry, interpretation of cost-effectiveness is complicated by the lack of consensus with regard to effectiveness endpoints. In most fields of therapy, clinical effectiveness is primarily measured in terms of life years gained and/or quality-adjusted life years (QALYs) gained, although secondary endpoints such as complications avoided or time to clinical worsening/onset of complications are also frequently used. However, these endpoints are generally not appropriate for use in the field of prosthetic dentistry; instead, previous studies

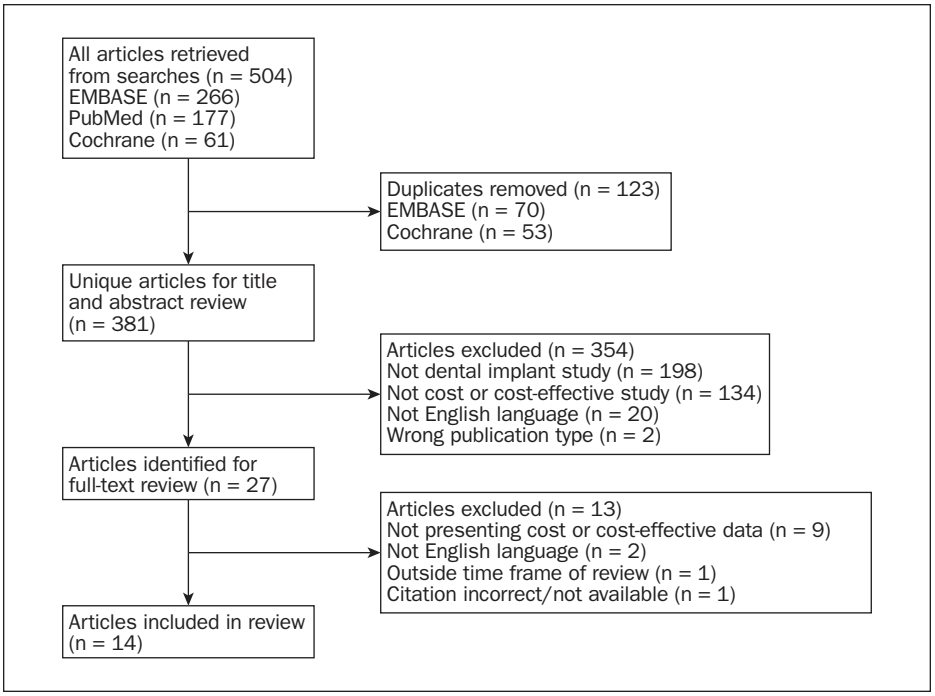

Fig 1 Summary of literature search results.

have used a wide variety of methods to estimate cost-effectiveness, including cost per functional unit in position, incremental cost per quality-adjusted prosthesis year (QAPY), and incremental cost per unit improvement in masticatory ability. Consequently, the objective of the current review was to identify recently published studies on cost and cost-effectiveness with the aim of gaining an overview of the cost-effectiveness of dental implants in comparison with other available treatment options in prosthetic tooth replacement for both single-tooth replacement and the treatment of partially and completely edentulous patients.

MATERIALS AND METHODS

A systematic literature review was performed using the PubMed, EMBASE, and Cochrane library databases. The aim of the literature review was to identify studies on cost and cost-effectiveness relating to dental implants. The literature search was based on Medical Subject Heading (MeSH) terms. The following search terms were used to search the PubMed database: ("Dental Prosthesis" [MeSH] OR "Dental Restoration, Temporary" [MeSH] OR "Dental Restoration, Permanent" [MeSH] OR "Dental Implantation" [MeSH] OR "Dental Implants" [MeSH] OR "Mandibular Prosthesis Implantation" [MeSH] OR "Periodontium" [MeSH] OR "Prosthodontics" [MeSH]) AND "Costs and Cost Analysis" [MeSH]) NOT (Editorial [Publication Type] OR Letter [Publication Type] OR Case Reports [Publication Type] OR Comment [Publication Type]). In addition, studies were also required to have been published after November 2000 and in English. This search strategy was subsequently adapted for use in both the EMBASE and Cochrane Library databases. For inclusion, studies were required to report data relating to the direct costs (either initial treatment costs, total costs, or long-term disaggregated costs) or cost-effectiveness of implant-based prostheses used for the replacement of either single or multiple teeth.

Owing to the heterogeneity of cost-effectiveness endpoints used in studies on dental implants (eg cost per QALY gained, cost-per QAPY gained, cost per functional unit in place, cost per unit improvement in masticatory ability) no restrictions were applied with regard to reporting of cost-effectiveness endpoints. No restriction was applied in terms of patient characteristics, as such studies on patients requiring single-tooth replacement and on patients with fully edentulous mandibles and/or maxillae were included; studies on healthy patients and those with periodontal disease were also included. In addition to the databases mentioned, the reference section of each short-listed article was reviewed for studies on cost and cost-effectiveness, and additional hand searches were also performed.

A total of 381 unique articles were identified (Fig 1). An initial screening of titles and abstracts was performed, followed by more detailed full-text screening of short listed articles. A total of 14 studies on cost/cost-effectiveness were identified via the literature searches. The quality of studies included in the review was assessed using the Drummond checklist, which

Table 1 Summary of Studies Investigating the Economic Outcomes Associated with the Use of Dental

Study (y)	Setting, currency	Study description and methodology
Bouchard et al (2009)[19]	France, 2007 €	Cost-effectiveness analysis of a dental implant strategy versus an FPD for first-line single-tooth replacement
		Cost-effectiveness determined via assessment of cost per functional unit in position
		Analysis performed over 20 y
		Quality assessment score 15/33
Brägger et al (2005)[24]	Switzerland, CHF (cost year not stated)	Comparison of total costs and resource use for single-tooth replacement with either three-unit FPDs or single crowns on implants
		The study examined the total no. of visits required, total treatment time, and total cost for both treatments
		Quality assessment score 15/30
Incici et al (2009)[23]	Switzerland, CHF (cost year not stated)	Assessment of long-term costs associated with oral rehabilitation in young adults with birth defects affecting the formation of teeth
		Linear regression analysis performed to determine initial treatment cost per tooth replaced for implant-based reconstructions and reconstructions on teeth
		Long-term cumulative treatment costs and complication/failure rates were also assessed
		Quality assessment score 15/30

FPD = fixed partial denture.

assesses the quality of health economic studies based on a number of parameters, including the rationale for and type of evaluation performed; methods used; source of and input parameters used; and outcomes reported (See appendix 1, available online at www.quintpub.com/journals).[22]

RESULTS

Due to the heterogeneity of the studies identified, studies were divided into those assessing the costs/cost-effectiveness of the use of dental implants in single-tooth replacement and those investigating the costs/cost-effectiveness of implant-supported and implant-retained overdentures. Additionally, although the literature search was designed to specifically capture studies on cost and cost-effectiveness, a number of studies were identified that examined patient willingness to pay and patient-perceived costs; the findings of these studies are discussed in a separate section.

It should be noted that in the present review, no pooled analysis or meta-analysis was performed due to the heterogeneity of the patient populations under investigation, the study designs, and the endpoints reported.

Cost and Cost-Effectiveness of Dental Implants for Single-Tooth Replacement

A total of three studies focusing on the costs/cost-effectiveness of dental implants for single-tooth replacement were identified (Table 1). These studies reported inconsistent findings; two reported that dental implants were cost-saving or cost-effective compared with fixed dental prostheses,[19,23,24] while the third concluded that there was no significant difference in the cumulative costs of tooth-based compared with implant-based reconstructions.[23] The quality of these health economic studies was assessed using the Drummond checklist,[22] and overall quality was low due largely to a lack of description regarding methodology. In a French analysis by Bouchard et al, the authors reported that, over a period of 20 years, dental implants were the dominant treatment option versus fixed prostheses for first-line single-tooth replacement (ie, associated with lower costs and improved clinical outcomes versus tooth-supported prostheses).[19] In their analysis, it was assumed that patients had a dental implant for the replacement of a missing first molar at the mandible or a fixed partial denture and that the teeth bordering the edentulous area were "pristine."[19] However, the authors note that a limitation was that there was a notable disparity among clinicians in the results of the cost survey used to estimate the costs for fixed partial denture and implant treatment.

Additionally, in a similar study, Brägger et al retrospectively analyzed treatment costs associated with three-unit fixed partial dentures or single crowns on implants in consecutive patients requiring single-tooth replacement in private practice.[24] Although implant treatment required more initial treatment visits, total costs were statistically significantly lower ($P < .003$) in the implant group in comparison with the fixed partial

Implants for Single-Tooth Replacement
Key results
Over 20 y, implants were projected to be associated with lower total costs (€ 3,517 versus € 4,385) and higher success rates (92% vs 69%) in comparison with FPDs for single-tooth replacement
The cost per functional unit in position was € 3,819 for implants and € 6,286 for FPDs
Implants were the dominant treatment strategy compared with FPDs for single-tooth replacement in the French setting
Treatment with implants was associated with a higher no. of visits (8.1) vs FPDs (4.8), but overall total chairtime was similar for both treatment groups
Over a short observation period (1 to 4 y), implants were associated with lower overall costs (CHF 3,939) versus tooth-supported prostheses (CHF 3,218)
Greater laboratory costs in the tooth-supported group were a key driver of the higher overall costs in this group
The initial treatment cost per tooth replaced was equal to CHF 3,369 + (CHF 1,183 × units) for reconstructions on implants and CHF 731 + (CHF 811 × units) for reconstructions on teeth
58% of tooth-supported reconstructions remained complication/failure-free over a median observation period of 15.7 y; 47% of implant-supported reconstructions remained complication/failure-free over a median observation period of 8 y
Long-term cumulative treatment costs were not statistically significantly different between patients treated with implants and tooth-based reconstructions

denture group, which was driven mainly by higher laboratory costs.[24] In the remaining study, Incici et al investigated the cumulative long-term costs associated with the oral rehabilitation of young adults with birth defects affecting the formation of teeth (amelogenesis/dentinogenis imperfecta, hypodontia/oligodontia, and cleft lip and palate). The initial treatment cost per tooth replaced was CHF 3,369 + (CHF 1,183 × units) for reconstructions on implants and CHF 731 + (CHF 811 × units) for reconstructions on teeth. However, the difference in cumulative treatment costs between the two groups was not statistically significant.[23]

Overall, studies showed that for single-tooth replacement, dental implants represent a cost saving or cost-effective treatment option in comparison with crown or fixed partial denture restoration.

Cost-Effectiveness of Dental Implants for the Replacement of Multiple Teeth

The literature identified showed that implant-retained and implant-supported overdentures in patients with edentulous mandibles are associated with higher initial treatment costs but greater effectiveness (measured either in terms of improved masticatory ability, OHRQoL, or QAPYs) in comparison with conventional dentures. Additionally, comparisons of different types of implant-based prostheses (eg, implant-supported versus implant-retained overdentures) showed implant-supported prostheses to be associated with higher costs but greater effectiveness in comparison with implant-retained prostheses (Table 2). Overall, the quality of studies was low, again mainly due to a lack of description with regard to methodology and the fact that a large proportion of studies were conducted retrospectively and therefore did not consider discounting of future costs and clinical outcomes. However, three studies scored relatively high on the quality assessment checklist: Zitzmann et al[35] (score 22/31), Attard et al[26] (score 23/32), and Attard et al[25] (score 25/33).

Two studies conducted by Zitzmann et al were conducted in the Swiss setting and compared the cost-effectiveness of implant-supported overdentures, implant-retained overdentures, and conventional complete dentures in mandibular edentulous patients.[34,35] A total of 60 edentulous patients who required treatment in the edentulous mandible with removable prostheses, with or without implants, were included in the analyses. The 2006 Zitzmann et al study[35] achieved one of the highest scores in the quality assessment checklist; quality assessment was not performed on the 2005 study by Zitzmann et al[34] as it presented preliminary short-term results of the 2006 analysis. In the short-term analysis published in 2005, the measure of effectiveness used was improvement in masticatory ability at 6 months posttreatment, whereas the long-term analysis published in 2006 assessed effectiveness in terms of QAPYs gained.[34,35] The 2006 analysis was performed over a period of 10 years (with future costs and clinical outcomes discounted at 3% per annum), and effectiveness was measured in terms of QAPYs based on dental health state preference at baseline and at 6 months and 3 years posttreatment. It was assumed that dental health state preference would remain stable from year 3 onward. Costs were based

Table 2 Summary of Cost and Cost-Effectiveness Studies on Implant-Based Prostheses Versus FPD-Based Prostheses

Study (y)	Setting, currency	Study description and methodology
Attard et al (2003)[25]	Canada, 1995 CAD	Cost-minimization analysis of implant-supported overdentures versus fixed osseointegrated prostheses in edentulous patients The direct clinical and time costs assessed over a period of 9 y (initial treatment costs and annual maintenance costs were assessed as was duration of each clinic visit) The analysis was performed from a patient's perspective Quality assessment score 25/33
Attard et al (2005)[26]	Canada, 2002 CAD	Evaluation of the long-term costs associated with mandibular implant-supported prostheses (both fixed prostheses overdentures) The analysis was performed over a period of 10 y, and costs were discounted at a rate of 3% per annum The patient population consisted of prosthetically maladaptive patients (ie, patients who had been edentulous for at least 5 y and were referred for treatment owing to chronic inability to wear prostheses) Quality assessment score 23/32
Chaffee et al (2002)[27]	United States, $ (cost year not stated)	Evaluations of the maintenance (time and costs) required to provide acceptable and satisfactory implant-retained mandibular overdentures Patient population consisted of completely edentulous patients aged 35 to 75 y (patients with evidence of pathologic processes of the mandible or a history of recurrent apthous ulceration or recurrent mucosal irritation) All patients received new maxillary and mandibular complete dentures followed by placement of implants in the mandibular left and right canine at 3 mo Quality assessment score N/A – focus of study on amount of maintenance visits required
Heydecke et al (2005)[28]	Canada, 1999 CAD	Cost-effectiveness analysis of mandibular conventional dentures versus two-implant overdentures in patients aged 65 to 75 y Patient population consisted of individuals who had been edentulous for the past 5 y Future costs and clinical outcomes were discounted at 3% per annum Quality assessment score 20/30
MacEntee et al (2005)[29]	Canada, (cost year not stated)	Assessment of patient satisfaction and maintenance costs over a 3-y period in patients with implant-retained mandibular overdentures who previously had conventional complete dentures Patient satisfaction was assessed using a VAS prior to treatments and at posttreatment (1 mo and 1 and 2 y) Quality assessment score – N/A, study primarily designed to assess patient satisfaction and maintenance requirements
Palmqvist et al (2004)[30]	Denmark, $ (cost year not stated)	Evaluation of resource use and costs of implant-supported fixed prostheses vs overdentures (retained by a Dolder bar system) in patients with an edentulous mandible Quality assessment score N/A – focus of study on comparison of clinical working hours
Stoker et al (2007)[31]	The Netherlands, 2000 €	Analysis of initial treatment costs and long-term (8 y) maintenance costs in patients with three different types of implant-retained overdentures (bar on four implants, bar on two implants, or ball attachments on two implants) Study population consisted of edentulous individuals with atrophic mandibles and persistent problems with conventional complete dentures The study did not evaluate quality of life or patient satisfaction Quality assessment score 20/28
Takanashi et al (2004)[32]	Canada, 1999 CAD	Cost comparison of mandibular two-implant overdenture treatment vs conventional dentures, within an academic teaching hospital setting Both direct and indirect costs were calculated Quality assessment score – see Heydecke et al[28]

Key results
Mean total, clinical, and time costs were statistically significantly greater for the fixed restoration group in comparison with the implant-supported overdenture group
Over a 9-y period, total costs in the fixed prosthesis group were significantly higher (CAD 7,984) than in the overdenture group
Initial treatment costs were also higher in the fixed prosthesis group (CAD 7,567 vs CAD 2,505; $P = .001$)
Maintenance costs were significantly higher in the fixed prosthesis group vs the overdenture group (CAD 2,527 vs CAD 830; $P = .001$)
Initial treatment and maintenance costs over the study period were higher for patients treated with fixed vs overdenture prostheses (due largely to the fact that patients in the fixed implant group required a higher no. of implants than those with implant-supported overdentures)
Of 58 patients in total, 6 required no adjustments: the remaining 52 patients required a total of 327 maintenance visits for prosthesis and/or abutment adjustments, estimated to require a total of 115 practitioner (clinic) hours
The mean maintenance cost (including all professional and laboratory services) was $218 per patient
35/58 patients required 85 visits for denture adjustments; mean (SD) no. of denture adjustments was 1.49 (1.92) per patient, and mean (SD) time from baseline to first adjustment was 89.5 (297) days
35/58 patients required 88 visits for adjustments of ball housings; mean (SD) no. of adjustments was 2.51 (1.72) per patient and mean time from baseline to first adjustment was 9.86 mo
13/58 patients required 27 visits to replace broken/debonded prosthetic teeth; mean (SD) no. of tooth repairs per patient was 0.44 (1.81)
18 patients required 20 mandibular relines (mean, 0.34 relines per patient); 16 patients required 18 maxillary prosthesis relines (mean, 0.31 relines per patient)
Equalized annual costs were CAD 399 for conventional dentures compared with CAD 625 for implant overdentures ($P < .001$)
Equalized annual values for effectiveness, measured by OHIP-20 score were 47.0 for conventional dentures vs 31.3 for implant overdentures ($P < .05$)
Mean treatment cost during the first year was CAD 2,957 for conventional dentures versus CAD 3,650 for implant overdenture treatment; implant treatment was associated with an annual incremental cost of CAD 14 to improve OHRQoL by 1 OHIP-20 point
Patient satisfaction posttreatment was significantly greater vs pretreatment, but there were no significant differences between patients with different attachment mechanisms or patients with or without a reinforcing framework
Clinical working hours were greater in the overdenture group (4.1 h) vs the fixed prosthesis group (3.1 h), but mean laboratory working hours were greater in the fixed prosthesis group (12.5 h) vs the overdenture group (7.7 h)
Costs were higher in the fixed prosthesis group ($1,700) versus the overdenture group ($1,350)
Initial treatment costs (up to 3 mo after insertion of overdenture) constituted 75% of total treatment costs
Initial costs were highest in the group with a bar on four implants (€ 3,564), followed by two implants on a bar (€ 2,602), followed by two implants on ball attachments (€ 2,413)
Mean direct costs were CAD 2,332 for the two-implant overdenture group compared with CAD 814 for conventional dentures
Mean total costs were CAD 4,245 for two-implant overdentures and CAD 2,316 for conventional dentures

Table 2 Summary of Cost and Cost-Effectiveness Studies on Implant-Based Prostheses Versus FPD-Based Prostheses *(continued)*

Study (y)	Setting, currency	Study description and methodology
Walton et al (2009)[33]	Canada, CAD (cost year not stated)	Comparison of patient satisfaction, component costs and treatment/maintenance time in patients with mandibular overdentures retained by either one or two implants
		Patient satisfaction was assessed using a VAS before implant treatment and at 2 mo and 1 y after implant treatment
		Quality assessment score – N/A, evaluation primarily designed to assess patient satisfaction and maintenance requirements
Zitzmann et al (2005)[34]	Switzerland, 2000 CHF	Preliminary results of an economic evaluation comparing the cost-effectiveness of implant-retained (two implants) overdentures, implant-supported overdentures (four implants), or conventional complete dentures
		The analysis was conducted from the patient's perspective and the time period was 6 mo; patients were edentulous and required treatment for an edentulous mandible.
		Effects were measured as improvements in perceived masticatory ability compared with pretreatment
		Quality assessment score – see Zitzmann et al[35]
Zitzmann et al (2006)[35]	Switzerland, 2000 CHF	Cost-effectiveness analysis of implant-retained overdentures, implant-supported overdentures, and conventional dentures
		The analysis was performed over a period of 10 y, and future costs and clinical outcomes were discounted at 3% per annum
		Quality assessment score 22/31

FPD = fixed partial denture; N/A = not applicable; VAS = visual visual analog scale; SD = standard deviation; OHIP = Oral Health Impact Profile; OHRQoL = oral health-related quality of life; ICER = incremental cost-effectiveness ratio; QAPY = quality-adjusted prosthetis year.

on the national dental tariff structure and included implant material, surgical and prosthodontic treatment, and laboratory fees; indirect costs including patient transport and lost time due to treatment were also included in the analysis. In both analyses, implant-supported overdentures were the most costly but most effective treatment option. Total costs over the 3-year period were CHF 3,675 for complete dentures, CHF 8,874 for implant-retained overdentures, and CHF 17,837 for implant-supported overdentures (costs in year 2000 CHF).[35] Patients in the implant-supported and implant-retained overdenture groups had worse dental health scores at baseline (0.35 and 0.37, respectively) compared with those in the complete denture group (0.52). However, at 3 years posttreatment dental health state preference was greater in those treated with implant-retained and implant-supported overdentures (0.83 and 0.91, respectively) in comparison with those treated with conventional overdentures (0.81). Therefore, in terms of cost-effectiveness, over a period of 10 years implant-retained overdentures were associated with an incremental cost of CHF 5943, but an incremental benefit of 1.46 QAPYs versus conventional dentures. This resulted in an incremental cost-effectiveness ratio (ICER) of CHF 3,810 per QAPY gained for implant-retained overdentures versus conventional dentures.[35] Similarly, a comparison of implant-supported versus implant-retained overdentures showed that implant-supported overdentures were associated with an incremental cost of CHF 8,950 and a gain of 0.40 QAPYs in comparison with implant-retained overdentures, leading to an ICER of CHF 22,375 per QAPY gained for implant-supported versus implant-retained overdentures.[35]

In similar analyses conducted in the Canadian setting, Takanashi et al[32] and Heydecke et al[28] examined the costs and cost-effectiveness, respectively, of conventional mandibular overdentures in comparison with two-implant overdentures in patients aged 65 to 75 years who had been edentulous for the past 5 years.[27,28] The analysis included both direct (labor, materials, drugs, laboratory work, and radiography) and indirect costs (patient transport costs and costs associated with the loss of a patient's time due to treatment). In both studies, treatment costs were notably higher in patients with two-implant overdentures in comparison with those with conventional dentures. In the analysis by Heydecke et al, two-implant overdentures were associated with an annual incremental cost of CAD 14 to improve OHRQoL by 1 Oral Health Impact Profile-20 (OHIP-20) point in comparison with conventional dentures.[36]

Key results
Improvement in patient satisfaction was statistically significant in both groups but the difference between the one implant and two-implant group was not significant
Total maintenance time was similar for both groups, but the single-implant group had significantly lower component costs ($P < .001$) and surgery times (P .002)
Mean incremental costs for implant-retained and implant-supported overdentures in comparison with conventional dentures were CHF 4,329 and CHF 13,360, respectively
Mean incremental improvement in masticatory ability at 6 mo was 19% in the implant-retained group and 23% in the implant-supported group compared with conventional dentures
Mean ICER was CHF 228 and CHF 581 per percentage-point increase in masticatory ability for implant-retained and implant-supported overdentures versus conventional dentures
Initial treatment costs were CHF 6,935 for implant-retained overdentures, CHF 15,805 for implant-supported overdentures and CHF 2,525 for conventional dentures
At 3 y posttreatment, quality of life was better in those with implant-supported overdentures (0.91) vs those with implant-retained overdentures (0.83) and conventional complete dentures (0.81)
Over a period of 10 y implant-retained overdentures were associated with an ICER of CHF 3,810 per QAPY gained versus conventional dentures. The ICER for implant-supported overdentures versus implant-retained overdentures was CHF 22,375 per QAPY gained

A number of analyses identified in the review compared the cost-effectiveness of different types of implant-based prostheses. For example, Attard et al examined the costs associated with implant-supported overdentures versus fixed osseointegrated mandibular prostheses in patients described as being prosthetically maladaptive (ie, patients who had been edentulous for the past 5 years and who had been referred owing to their chronic inability to wear prostheses).[25,26] In both studies, initial treatment and maintenance costs were higher for patients with fixed prostheses compared with those with overdentures (initial costs included the cost of implants, abutments, and frameworks as well as the time of oral surgeons and prosthodontists; maintenance treatment costs included costs associated with annual scheduled visits as well as costs associated with the treatment of complications).[25,26] However, in the 2005 analysis,[26] Attard et al noted that patients in the fixed prosthesis group typically had a greater number of implants, which was a major contributing factor in the higher overall costs. In both studies, the authors concluded that overdentures are the most cost-effective treatment option for edentulous patients in the Canadian setting. Both analyses were performed using retrospective patient data, with the 2003 analysis focusing exclusively on patients who received implants over the period 1979 to 1982[25] and the 2005 analysis comparing outcomes in patients receiving treatment in the 1980s versus those receiving treatment in the 1990s.[26] Attard et al showed that the treatment burden associated with dental implant treatment lessened once surgical and maintenance protocols became established, with surgical techniques and the materials used in the fabrication of prostheses having improved considerably since the early 1980s. The authors reported a 62% difference in maintenance costs between patients receiving treatment prior to 1990 versus those receiving treatment after 1990. This, in turn, suggests that retrospective studies may overestimate the current treatment burden associated with the placement of dental implants and associated prosthetic reconstructions (more recent advances in implant design and prosthetic components have decreased complications).[26]

Stoker et al investigated initial treatment and maintenance costs of three different types of implant-retained overdentures (bar on four implants, bar on two implants or ball attachments on two implants) in edentulous individuals with atrophic mandibles and persistent problems with conventional dentures). Initial costs (costs incurred in the 3 months postinsertion of the overdenture including chair time and costs for care

Table 3 Summary of Studies on Patient Satisfaction, Willingness to Pay, and OHRQoL

Study (y)	Setting	Study description and methodology
Brennan et al (2010)[39]	Ireland	Comparison of patient satisfaction and OHRQoL in patients with implant-supported overdentures and complete implant fixed prostheses (mandible or maxilla) OHRQoL was assessed using the OHIP-14 questionnaire
Esfandiari et al (2009)[18]	Canada	Assessment of patient preferences in edentulous elderly patients in terms of willingness to pay and willingness to accept dental implants Patients questioned had maxillary dentures and either a mandibular conventional denture or a two-implant overdenture with ball attachments
Nickenig et al (2008)[40]	Germany	Assessment of OHRQoL in partially edentulous patients before and after implant therapy OHRQoL was assessed using the German version of the OHIP-21 questionnaire
Tepper et al (2003)[16]	Austria	The authors conducted structured interviews with 1,000 adults in the general population with regards to patient-perceived cost and patient satisfaction with dental implants

OHIP, Oral Health Impact Profile; OHRQoL, oral health-related quality of life; VAS, visual analog scale

provided by oral and maxillofacial surgeons, prosthodontists, oral hygienists, and dental technicians; as well as all materials, equipment, and disposables used; indirect costs were not included) constituted approximately 75% of overall treatment costs, and initial treatment costs were higher for patients with implant-retained overdentures on four versus two implants.[31] Additionally, previously published data showed that over an 8-year period, overall patient satisfaction was high and driven mainly by the stability and retention of the mandibular overdenture. However, at 8 years post–implant placement, patients with two implants and ball attachments were less satisfied with retention and stability of the overdenture in comparison with those with splinted implants.[37] These findings largely concur with a study by Naert et al, which compared patient satisfaction in patients with mandibular overdentures retained on either magnets, ball attachments or straight bars.[38] Patient satisfaction was similar across all three patient groups but the bar attachment group had higher retention capacity and fewer prosthetic complications than the other groups.[38]

Patient Satisfaction, Willingness to Pay, and OHRQoL

Studies on quality of life, patient perception of costs, and willingness to pay showed that dental implants were associated with improvements in masticatory function and OHRQoL in comparison with conventional dentures; patient satisfaction with implants was generally high and edentulous patients were generally willing to pay up to three times the cost of conventional dentures for dental implants.

Although the literature search was not specifically designed to capture studies on quality of life, a total of six articles that focused on patient satisfaction, patient perceptions of cost, willingness to pay, and OHRQoL were identified (Table 3).

The perceived cost of dental implant treatment is sometimes cited as a major barrier precluding patients from considering dental implants as a treatment option. However, a study by Tepper et al in the general population showed that few people were aware of the actual cost of dental implants or of the determinants of treatment costs.[16] Moreover, Esfandiari et al conducted a survey on willingness to pay in elderly patients with maxillary dentures and either a mandibular conventional denture or a two-implant–supported overdenture[18] and reported that 46% of those with conventional dentures and 70% of those with implants were willing to pay three times the price of conventional dentures for implants, rising to 77% and 96%, respectively, if payment by installment was an option.[18] In comparison, Tepper et al reported that 79% of respondents in the general population thought that the cost of dental implants was too high, although knowledge of the actual cost of implants was low.[16]

Four articles were identified relating to OHRQoL and patient satisfaction with implants. In a Canadian study, MacEntee et al assessed patient satisfaction in subjects with implant-retained overdentures who had previously received conventional complete mandibular dentures and reported a statistically significant improvement in patient satisfaction following treatment.[29] A related study by Walton et al reported that there was no significant difference in patient satisfac-

Key results
Overall satisfaction scores were significantly lower in the implant overdenture group ($P = .01$)
OHRQoL was generally better in patients with fixed prostheses compared with those with a removable prosthesis
Key limitation of the OHIP-14 questionnaire is that it does not assess masticatory ability
46% of conventional denture wearers vs 70% of implant-treated patients were willing to pay three times the cost of dentures for implant treatment, which increased to 77% and 96%, respectively, if payment by installment was an option
Prior to implant therapy, OHRQoL was significantly lower in partially edentulous patients in comparison with the general population
Assessment of post–implant therapy OHRQoL showed a significant improvement.
97% of respondents felt that missing teeth should be replaced in adults, but 79% of respondents thought that the cost of dental implants was too high
Overall patient acceptance varied with age and was highest in respondents aged < 30 y (73%) and lowest in those aged > 50 y (51%)
In respondents who already had dental implants, 62% and 51% were "very satisfied" esthetically and functionally with their implants

tion between those with dentures retained by one or two implants.[33]

Nickenig et al assessed OHRQoL in partially edentulous patients before and after implant treatment in comparison with that of a fully dentate control group using a German version of the OHIP-21 questionnaire.[40] The median OHIP-21 score was 17.1 before treatment, and patients most frequently expressed concerns relating to difficulty with mastication, psychologic problems associated with appearance, and worrying about dental problems. Following treatment, the median OHIP-21 score improved significantly ($P < .01$) to 5.4 (in comparison, the median OHIP-21 score in the fully dentate control group was 3.4).

DISCUSSION

Overall, the benefits of treatment with dental implants such as reduced prosthesis mobility, decreased bone resorption, and improved masticatory function lead to better OHRQoL in comparison with conventional dentures in edentulous (maxilla, mandible, or both) patients. Additionally, for single-tooth replacement, dental implants are generally either cost-saving or cost-effective in comparison with fixed partial denture restorations.

There is a general paucity of data from studies on cost-effectiveness in the area of prosthetic dentistry. Furthermore, direct comparison in this area is complicated by heterogeneity in terms of effectiveness endpoints used, costs included, patient population, and time frame. Comparison of findings between settings is further complicated by cultural differences between settings in terms of attitudes toward the replacement of lost teeth, the availability and affordability of dental care, pricing policy and level of reimbursement of dental implants, as well as the discount rate applied to cost-effectiveness analyses. Additionally, a substantial proportion of studies were performed over short-term periods and, consequently, will not capture costs of complications and/or failures that may only manifest after several years. In the studies cited, effectiveness measures have included masticatory ability, QAPYs and OHRQoL, measured using the OHIP-20 scale.

Additionally, a number of studies reported outcomes based on retrospective patient data. Prosthetic dental technology has evolved rapidly since the inception of dental implants in the late 1970s and early 1980s such that two-implant overdentures are now recommended as the standard of care for patients with edentulous mandibles. Consequently, it is feasible that a number of retrospective studies included in the current review may have overestimated the maintenance and/or initial costs associated with prosthetic dental restoration, not only stemming from improved manufacturing techniques and decreased complications but also a decrease in cost of several components and chair time. In particular, there have been notable advances in the materials and technologies used to fabricate dental implants, resulting in improved osseointegration with decreased complication and failure rates. There is a large body of research focusing on utilizing surface coatings on titanium implants to improve rates of osseointegration, and research into the use of biomolecules such as bioadhesive motifs or growth factors as surface coatings is also ongoing. For example,

coating implant surfaces with calcium phosphates has been shown to improve rates of osseointegration in vivo.[41] In addition, there have been notable advances in materials including SLActive (Straumann), which is associated with greater bone apposition, and Roxolid (Straumann), a titanium-zirconia alloy that has been shown to have higher tensile and fatigue strengths in comparison with pure titanium.[42,43] Technologic advances have meant that the number of implants/bars required to support overdentures has decreased, which in turn has decreased the costs associated with dental implants for a considerable proportion of patients. Another important advance has been the use of CAD/CAM milling (as opposed to conventional gold casting) for the fabrication of prosthetic restorations. CAD/CAM milling accuracy is high (typically in the region of 50 μm) and greatly reduces the time and resources required for the fabrication and placement of dental prostheses along with decreased materials cost of titanium and zirconia when compared with high noble metals. However, in addition to advances in implant therapy there have also been notable technologic advances in conventional therapy, including microsurgical techniques, electronic apex locators, and the use of cone beam computed tomography, which may not be captured in earlier analyses and may impact both costs and success rates.

The overall quality of economic analyses in prosthetic implant dentistry was generally low, with only two analyses providing ICERs. Zitzmann et al[35] reported an ICER of CHF 3,810 per QAPY gained for implant-retained overdentures versus conventional dentures and CHF 22,375 per QAPY for implant-supported–overdentures versus implant-retained overdentures in the Swiss setting. In the Canadian setting, Heydecke et al[28] reported that the use of two-implant supported overdentures was associated with an annual incremental cost of CAD 14 per OHIP-20 point gained in comparison with conventional dentures. However, the study by Zitzmann et al was the only study to discuss the ICERs for implant-retained and implant-supported overdentures versus conventional dentures in the context of willingness-to-pay thresholds.[35] Over a time horizon of 10 years, the probability of implant-retained overdentures being considered cost-effective versus conventional dentures at a willingness-to-pay threshold of CHF 3,800 per QAPY gained was approximately 50%. In the study that examined willingness to pay among partially edentulous elderly patients (previously treated with conventional dentures), the authors found that over three-quarters of those with implants were prepared to pay three times the cost of conventional dentures for dental implants.[18] Interestingly, this study was conducted in patients above retirement age, many of whom typically have limited financial resources, which suggests that patient satisfaction in this group is particularly high. Although willingness to pay was has been investigated from a patient perspective, there is a general paucity of studies investigating willingness to pay for dental implants from the perspective of third party health care providers. There was also an absence of studies mapping quality of life data to established instruments such as the EQ-5D and the Health Utilities Index 3 (HUI3), which would enable health economic studies in the area of prosthetic dentistry to present the benefits of new treatments in terms of QALYs gained, a commonly used measurement in health economic assessment of new interventions. Another underlying theme of the present review was that the number of dental implants placed is a major determinant of the cost-effectiveness of dental implants, with dental implants generally representing a cost-effective or even cost-saving treatment option versus crowns or tooth-supported prostheses for single-tooth replacement. Of the three studies that assessed dental implants in single-tooth replacement, two[19,24] reported that dental implants were associated with lower overall costs than fixed partial dentures. The third study showed no significant difference in cumulative treatment costs between implant-based and tooth-based reconstructions.[23] Similarly, in those analyses that compared costs or cost-effectiveness of two- versus four-implant–retained or implant-supported overdentures, overdentures retained/supported on four implants were more expensive but more effective in terms of masticatory ability and OHRQoL compared with overdentures retained/supported on two implants.[25,26,31] The results of these analyses should, however, be interpreted with caution, as although implant-supported prostheses have been associated with lower failure rates in comparison with tooth-supported prostheses, 5-year success rates (defined as the absence of any complications) have also been reported to be lower with implant-supported versus tooth supported prostheses, which may likely have implications in terms of overall costs.[44]

It is also important to take into account the patient populations included in the analysis. Studies of implant-supported and implant-retained overdentures were performed in patients with mandibular and/or maxillary edentulism and there were variations within these populations. For example, the analyses of Attard et al were performed in patients described as prosthetically maladaptive, that is, patients who had been edentulous for at least 5 years previously and who were referred for treatment becasue of chronic problems with conventional dentures.[25,26] Additionally, a key limitation associated with the current analysis is that many of the studies do not differentiate (or perform subgroup analyses) between healthy patients and

those with periodontal disease. Moreover, it is possible that cost-effectiveness outcomes in these two populations may differ if variations in implant failure rates existed between the two groups. While some studies have shown no significant differences in implant failure rates between patients with and without periodontal disease, others have reported that implant failure rates are higher in patients in whom periodontal disease is present.[45,46] Another limitation common to cost-effectiveness analyses is that short-term data are used to project long-term outcomes, a caveat of which is that such analyses do not capture late complications or late failure of implants. In particular, peri-implantitis is one of the most common causes of late implant failure, the incidence of which is frequently not taken into account in cost-effectiveness analysis and which may have an impact on the findings of such analyses. In addition, cost-effectiveness analyses yield no information on the rationale for opting for one particular treatment modality over another—a factor that is often influenced by cost—nor do they take into account ethical aspects of esthetic dentistry in terms of the boundary between what is perceived as elective treatment and what is deemed necessary.

CONCLUSIONS

Implant-supported and implant-retained overdentures were associated with high levels of patient satisfaction and improved masticatory function and OHRQoL in comparison with conventional dentures. Although implant-supported and implant-retained overdentures may be associated with higher initial treatment costs, studies on cost-effectiveness suggest that implant-retained overdentures, in particular, are likely to represent a cost-effective treatment option in comparison with conventional dentures. For single-tooth replacement, the emerging consensus from the literature is that dental implants are likely to represent a cost-effective or even cost-saving treatment option in comparison with fixed partial restorations.

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Appendix 1 Drummond checklist for health economic evaluations	
	Yes/No
Research question is stated	
Economic importance of the research question is stated	
Viewpoint is clearly stated and justified	
Rationale for choosing comparators is clearly stated	
Alternatives being compared are clearly described	
The form of economic evaluation used is stated	
Choice of form of economic evaluation is justified in relation to the questions addressed	
Sources of effectiveness estimates are stated	
Details of the design plus results of the effectiveness study are given	
Details of the methods of synthesis or meta-analysis of estimates are given	
Primary outcomes for the economic evaluation are clearly stated	
Methods to value benefits are clearly stated	
Details of the subjects from whom evaluations were obtained were given	
Productivity changes (if included) are reported separately	
The relevance of productivity changes to the study question is discussed	
Quantities of resource use are reported separately from their unit costs	
Methods for the estimation of quantities and unit costs are described	
Currency and price data are recorded	
Details of currency of price adjustments for inflation or currency conversion are given	
Details of any model used are given	
The choice of model used and the key parameters on which it is based are justified	
Time horizon of costs and benefits is stated	
The discount rate is stated	
The choice of discount rate is justified	
An explanation is given if costs and benefits are not discounted	
Details of statistical tests and confidence intervals are given for stochastic data	
The approach to sensitivity analysis is given	
The choice of variables for sensitivity analysis is justified	
The ranges over which the variables are varied are justified	
Relevant alternatives are compared	
Incremental analysis is reported	
Major outcomes are presented in a disaggregated as well as aggregated form	
The answer to the study question is given	
Conclusions follow from the data reported	
Conclusions are accompanied by the appropriate caveats	