Long-term Clinical Outcomes and Cost-Effectiveness of Full-Arch Implant-Supported Zirconia-Based and Metal-Acrylic Fixed Dental Prostheses: A Retrospective Analysis

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Purpose: *To provide a long-term comparison of metal-acrylic and zirconia implant-supported fixed complete dental prostheses.* ***Materials and Methods:*** *Patients treated with a metal-acrylic or zirconia fixed implant prosthesis with a minimum 5-year follow-up were included. All complications were registered, along with events such as peri-implantitis and implant failure. Survival and all costs associated with the prostheses were assessed to provide an overall evaluation of each type of fixed implant prosthesis protocol.* ***Results:*** *Seventy-four rehabilitated arches (43 metal-acrylic, 31 zirconia, mean follow-up: 8.7 ± 3.37 years) were included. Delayed complications accompanied the metal-acrylic prostheses more frequently. In both groups, single tooth chipping/fracture was the most prominent minor complication, and incidence of multiple teeth and framework fracture was the most frequent major complication. Zirconia fixed implant prostheses demonstrated higher prosthetic survival rates than the metal-acrylic prostheses (93.7% ± 5.5% at 5 years vs 83.0% ± 11.1%). No difference was observed for peri-implantitis or implant failure. The initial cost for zirconia prosthesis fabrication was significantly higher than metal-acrylic hybrids (an estimated difference of $7,829 [P < .001]); however, due to reduced complication rates for the zirconia fixed implant prosthesis, maintenance and treatment for complications did not greatly differ between groups.* ***Conclusion:*** *Within the limitations, zirconia fixed implant prostheses presented higher initial costs than metal-acrylic hybrids, however, with satisfactory outcomes, reduction of overall complications, and superior survival rates.* Int J Oral Maxillofac Implants 2020;35:395–405. doi: 10.11607/jomi.7833

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The continuing population growth worldwide and the increase in the proportion of older individuals are leading to a rise in the need for the treatment of edentulism.[1] With the establishment of high success rates and the advantages that implant therapy offers over conventional denture therapy, implant-supported fixed complete dental prostheses have increasingly become popular for rehabilitations of edentulous arches, particularly in younger adults and those unable to cope with tissue-supported prostheses.[2–4] Some of the advantages provided by the fixed implant prostheses are comfort, aid in alveolar bone preservation, and substantial improvements in prosthetic function, adaptation, and stability.[5–8] Supporting this view, some authors have argued that a fixed implant prosthesis should be considered as the standard of care, especially in mandibular arches where limited osteomucosal support can jeopardize the retention of a conventional denture.[8]

Metal-acrylic hybrids are among the most-studied treatment protocols for restoration of an edentulous arch with a fixed implant prosthesis. Long track records of these hybrids have presented simplicity in their use, reduced cost, and ease in reparability.[9–11] However, their relatively high complication rates for denture teeth debonding, veneered acrylic fracture, and screw/abutment loosening are time-consuming for both patients and clinicians.[10,12–16] Fracture or wear of the reconstruction materials in resin-based suprastructure prostheses should be considered a predictable risk when considering these types of restorations.[10] These concerns can cause inconveniences and lead to financial challenges for both the patient and the restorative team, vastly influencing their decision in choosing the appropriate prosthesis.

Zirconia has been used in dentistry for more than a decade with different indications, such as endodontic dowels, dental implants, implant abutments, and crowns,[17] and zirconia-based materials have gained considerable interest in the fabrication of fixed complete dentures to potentially address some of the problems that clinicians and patients previously encountered with the metal-acrylic hybrids. Additionally, zirconia has gained popularity as an alternative to metal frameworks in the fabrication of fixed implant-supported prostheses for its high biocompatibility, lower accumulation of plaque and bacteria on its surface, high flexural strength, and reduced staining compared with acrylic resins.[12,18,19]

The computer-aided design/computer-aided manufacturing (CAD/CAM) routinely used in fabricating a zirconia prosthesis allows for a superior fit of the prosthesis compared with the conventional metal-acrylic hybrids.[12] Among the advantages of this technology are the ability to predictably fabricate a full-arch prosthesis entirely in the virtual world while automatically storing the designs[20]; high biocompatibility, superior precision design, and higher accuracy.[20–23] However, challenges have also been associated with zirconia prostheses, which include: heavier weight compared with metal-acrylic prostheses[12] and difficulty in adjusting and polishing the framework.[24] Additionally, as insufficient long-term evidence currently exists on the clinical efficacy of implant-supported zirconia prostheses,[12,25] caution in regard to extensive implant-supported zirconia frameworks should be exercised.

Furthermore, in addition to accuracy and clinical predictability, it is also critical for any new technology to be proven cost-effective, particularly in the long term. Therefore, the aim of the present retrospective study was to identify the incidence of biologic and prosthetic complications associated with screw-retained metal-acrylic and zirconia fixed implant-supported prostheses, to evaluate the cost-effectiveness of the two treatment modalities, and lastly, to compare the two treatment protocols, investigating their clinical outcomes.

MATERIALS AND METHODS

The present research was designed and performed by abiding to the principles presented in the Helsinki Declaration (1975), as revised in 2000, for biomedical research involving human subjects. The research protocol was approved by the Institutional Review Board (IRB) for Human Studies, School of Dentistry, University of Michigan, Ann Arbor, Michigan, USA (HUM00114382), and the article was prepared in compliance with the STROBE guidelines (Appendix 1; see Appendixes in online version of this article at quintpub.com).

This retrospective study included all patients treated with metal-acrylic and zirconia fixed implant prostheses at the School of Dentistry, University of Michigan. All paper and digital patient files treated with implant-supported metal-acrylic and zirconia fixed implant prostheses were carefully scanned and analyzed by two authors (S.B., H.A.). During each stage, an expert (J.G.) was consulted in case of a disagreement. The inclusion and exclusion criteria that were applied are described as follows:

Inclusion criteria:

- Patients treated with full-arch metal-acrylic and zirconia fixed implant prostheses with a documented follow-up of ≥ 5 years
- Full-arch cases where all implants were placed within the same surgical procedure
- Presence of opposing occlusion
- Active patients enrolled in a maintenance schedule based on their individual needs and receiving at least one maintenance visit per year

Exclusion criteria:

- Subjects treated with a removable overdenture, an implant-retained overdenture, or porcelain-fused-to-metal restorations
- Inaccessible files due to any reason (deceased, bad debt) or charts with incomplete or unusable data
- Patients treated or maintained outside the University of Michigan School of Dentistry
- Prostheses supported by four implants
- Medically compromised patients (any past records of uncontrolled diabetes, radiation and/or chemotherapy treatment, psychologic problems), and severe bruxism cases (if stated or self-reported)

Data Collection and Classification

Within the review period, a screening of all full-arch fixed implant-supported prosthesis rehabilitations at the University of Michigan was performed, and the selected cases were divided into two groups depending on the type of prosthesis (metal-acrylic or zirconia). Patient information, such as age (at the time of surgery), sex, history of smoking (≥ 1 cigarette/day), diabetes (verified by checking full medical records), and history of periodontal disease were obtained along with other significant and correlated past medical diagnoses. History of periodontal disease, determined by reviewing the periodontal chart, was defined as the presence of at least four sites with clinical attachment loss (CAL) ≥ 3 mm and/or patients who had received professional treatment for periodontitis (scaling and root planing).[26,27] Additional data including time of implant placement, prosthetic loading protocol, number of implants and their characteristics, bone augmentation, flap procedures, and the type of prosthesis and/or the dentition in the opposing arches were registered.

The surgical, prosthodontic, and laboratory procedures that were followed are described in the Appendix 2.

Complications

All incidences of technical and biologic complications with their subsequent management were recorded at each visit and at the time of occurrence, and for comparison between the metal-acrylic and zirconia fixed implant prostheses, all possible complications were classified as follows.

Prosthetic Complications. All prosthetic complications, such as *(1)* fracture, dislodgment, chipping, or replacement of prosthetic teeth; *(2)* prosthesis fractures; *(3)* fracture of bars/frameworks; *(4)* loosening of abutment screws; and *(5)* replacement of prostheses were recorded and grouped into the following:

- Early or delayed prosthetic complications: Early prosthetic complications were defined as those occurring within 1 year of prosthetic loading, whereas delayed prosthetic complications were those that occurred 1 year after prosthetic placement.
- Minor and major prosthetic complications, and catastrophic failures: Minor complications were those that could be managed intraorally, and/or fixed chairside by the clinician within 24 hours of presentation, not requiring further laboratory processing or replacement. Major complications were ones that could not be managed or repaired chairside and required more extensive approaches (> 24 hours) and/or laboratory repair for their treatment. Catastrophic failure was the sudden and total failure of the prosthesis along with the dental implants from which recovery was impossible.

Biologic Complications. Biologic complications included the following:

- Denture-induced soft tissue complications, such as hyperplasia, prosthesis-induced ulcers, or pain were categorized into this group.
- Peri-implantitis and implant failure: The definition proposed by the 8th European Workshop on Periodontology in 2011 was adopted for peri-implantitis,[28] where clinical inflammation combined with the radiographic marginal bone loss of more than 2 mm after bone remodeling was indicative of the disease. The level of the peri-implant marginal bone was measured at baseline (after placement of the definitive prosthesis) and the final follow-up visit via calibrating the available periapical and panoramic radiographs using digital software (ImageJ, U. S. National Institutes of Health). Calibration was performed by the known length and/or diameter of each implant. All radiographic analyses were performed by one author (S.B.) and coded as a binary outcome of "yes" or "no" in a preformulated spreadsheet. In case of uncertainty, an expert reviewer (J.G.) was consulted for reassessing the radiographs. Additionally, if the patient had received treatment for peri-implantitis, that was also indicative of the disease. The presence of peri-implantitis was assessed and recorded per patient, and per individual implant. The incidence of peri-implantitis for an implant was recorded as a binary outcome (0 for a healthy implant, 1 for an implant showing signs of disease), and the percentage of diseased implants was calculated. Similar values were assigned to patients based on the presentation of peri-implantitis surrounding any of the implants (0 for a patient without any diseased implants, 1 if a patient showed signs of ≥ 1 diseased implant). Failure of an implant was defined in case of a lost, removed, or fractured implant and was calculated for each implant individually and then per patient, with the same methods described for peri-implantitis.[29]

Cost Analysis

The cost analysis was aimed at assessing all costs for diagnosis, repair, laboratory work, and maintenance as previously performed.[30] In summary, a standardized average for the cost relating to all performed procedures was determined throughout the entire follow-up for all prostheses and categorized as the initial cost (for implant placement procedures and prosthesis rehabilitation), the cost for complications (expenses related to

management of complications), and the total cost (the sum of the initial cost and the complication management). Detailed explanations on this analysis are presented in Appendix 2.

Statistical Analyses

Descriptive statistics were used to present data on complications and failures for each group. The demographic profile and clinical characteristics of the included sample were compared using: *(1) t* test analyses (*t*); *(2)* Chi^2 homogeneity tests (Chi^2); *(3)* Fisher's exact test (Fis); and *(4)* Mann-Whitney test (MW). For descriptive purposes, every edentulous arch corresponded to one case of an implant-supported fixed dental prosthesis.

Survival analysis was performed for the metal-acrylic and zirconia prostheses with the Kaplan-Meier function, estimating the cumulative survival rate (CSR) with 95% confidence intervals (CI). Survival was defined as the prosthesis remaining functional without replacement. Prostheses that needed to be refabricated for any reason were considered as failures. The Log Rank (Mantel-Cox) test was used for overall comparison of the survival curves.

The association between prosthetic complications across both study groups was analyzed using *(1)* descriptive analyses: number of cases (n), percentages (%), and mean ± standard deviation (SD); *(2)* a simple binary logistic regression model for each type of complication: estimation of unadjusted odds ratio (OR); and *(3)* a Mann-Whitney test for homogeneity test of distributions in continuous variables.

The probability of peri-implantitis and implant failure in both groups was calculated using a generalized estimation equation (GEE): estimation of odds ratio (OR) adjusted by smoking, history of periodontitis, and follow-up time. Cost analyses were performed using a generalized linear model: estimation of coefficients was adjusted by the number of implants and follow-up time (years).

RESULTS

Descriptive Analyses and Demographic Profiles

Three hundred fifty-two cases were initially identified based on the primary search on full-arch restorations. Among those, 278 were excluded due to the following reasons: *(1)* 119 cases with < 5 years follow-up; *(2)* 67 implant-retained overdentures; *(3)* 24 full-arch or multiple-unit tooth-supported dental prostheses; *(4)* 22 prostheses supported by four implants; *(5)* 15 files without or with unusable radiographs; *(6)* 9 cases with missing/unavailable postsurgical data; *(7)* 8 cases where the definitive prosthesis was placed or completed outside the University of Michigan; *(8)* 7 deceased patients; and *(9)* 7 unclear files with missing or incomplete data.

Finally, 74 full-arch prostheses (amounting to 56 patients, mean age of 52.9 ± 12.9 years) were included. Thirty-five patients had been treated with 43 metal-acrylic prostheses, while 21 patients had received 31 zirconia fixed implant prostheses. No statistically significant differences were observed with regard to age ($P = .7$) and sex ($P = .3$) between the metal-acrylic and zirconia groups.

Overall, 452 implants (252 in the metal-acrylic and 200 in the zirconia group) were included in the present study; 40.5% of the prostheses were restored with 6 implants (19 in metal-acrylic, 11 in the zirconia group); 33.9% of the prostheses were restored with 5 implants (18 in metal-acrylic, 17 in zirconia); 9.45% of the prostheses were restored with 7 implants (2 in metal-acrylic, 5 in zirconia), and 17.56% of the prostheses were restored with 8 implants (5 in metal-acrylic, 8 in zirconia). The average follow-up period was 104.7 ± 40.5 months for all the prostheses (118 ± 45.8 months for metal-acrylic, 90.9 ± 23.49 months for zirconia), with a median follow-up of 8 years.

Clinical Characteristics Among Groups

The difference in the follow-up time was significantly higher in the metal-acrylic group ($P < .01$). Clinical parameters such as implant loading (immediate vs delayed) and flapless surgery were significantly more associated with the zirconia restorations ($P < .01$ and $P < .05$, respectively). Conversely, the number of smokers, diabetics, patients with a history of periodontitis, and the location of the prosthesis (maxilla or mandible) were found not to be statistically different between groups ($P > .05$). The opposing arches of the metal-acrylic fixed implant prostheses consisted of 22 metal-acrylic hybrid prostheses, 6 conventional complete dentures, 1 implant-retained overdenture, 13 cases with a combination of teeth and crowns, and 1 removable partial denture. The opposing arches for the zirconia fixed implant prostheses included 28 implant-supported zirconia fixed prostheses, and 3 arches with a combination of teeth, crowns, and implants. The patient demographics and clinical characteristics are presented in Table 1.

Prosthetic Complications

A thorough overview of the prosthetic complications for both groups is presented in Tables A1 and A2 in Appendix 2.

Early and Delayed Complications

The incidence of early complications was not significantly different among both groups (23% of the

Table 1 Clinical Characteristics and Patient Demographics of Metal-Acrylic and Zirconia Fixed Implant Prosthesis Groups

	Fixed implant prosthesis group		
	Metal-acrylic (n = 43) (impl = 252)	Zirconia (n = 31) (impl = 200)	*P* value (test)
Follow-up (mo)	114.6 ± 47.1	86.35 ± 18.31	.006* (*t*)
Age (y)	58.8 ± 13.3	59.7 ± 12.6	.765 (*t*)
Male	23 (53.5%)	20 (64.5%)	.343 (Chi^2)
Smokers	4 (9.3%)	8 (25.8%)	.057 (Chi^2)
Diabetics	5 (11.6%)	2 (6.5%)	.692 (Fis)
History of periodontitis	9 (20.9%)	13 (41.9%)	.051 (Chi^2)
Maxillary rehabilitations	22 (51.2%)	18 (58.1%)	.557 (Chi^2)
Immediate implants	4 (9.3%)	0 (0.0%)	.135 (Fis)
Immediate loading	21 (48.8%)	1 (3.2%)	< .01* (Chi^2)
Open flap	23 (53.5%)	24 (77.4%)	.035* (Chi^2)
Bone augmentation	14 (32.6%)	11 (35.5%)	.793 (Chi^2)
No. of maintenance visits	9.9 ± 8.8	6.0 ± 3.1	.291 (MW)
Implant failure (patient)	10 (23.3%)	6 (19.4%)	.688 (Chi^2)
Implant failure (implant)	32 (12.7%)	19 (9.5%)	.303 (Chi^2)

Data are expressed in mean ± SD or percentage (%).
Chi^2 = Chi^2 homogeneity tests; Fis = Fisher's exact test; MW = Mann-Whitney tests; n = number of prostheses; impl = number of implants.*Statistically significant association.

Table 2 Comparison of Types of Complications and Statistical Analysis Between Both Groups of Prostheses

	Group			
	Metal-acrylic (n = 43)	Zirconia (n = 31)	OR (95% CI)	*P* value
Minor prosthetic complications	31 (72.1)	19 (61.3)	0.61 (0.23–1.64)	.329
Total minor prosthetic complications	3.4 ± 4.2	1.7 ± 2.7		.051 (MW)
Major prosthetic complications	18 (41.9)	8 (25.8)	0.48 (0.18–1.32)	.157
Total major prosthetic complications	0.8 ± 1.2	0.5 ± 1.0		.160 (MW)
Catastrophic failure	2 (4.7)	2 (6.5)	1.41 (0.19–10.6)	.736
Denture-induced soft tissue complications	12 (27.9)	4 (12.9)	2.16 (0.63–7.34)	.216
Early complications	10 (23.3)	10 (32.3)	1.57 (0.56–4.42)	.391
Delayed complications	31 (72.1)	16 (51.6)	0.41 (0.16–1.09)	.074

Data are expressed in mean ± SD, or percentage (%).
MW = Mann-Whitney tests; n = number of prostheses.

metal-acrylic prostheses, and 32.3% of the zirconia fixed implant prostheses, OR = 1.57, *P* = .391). Additionally, occurrence of delayed complications similarly lacked statistical significance between groups (*P* > .05). However, a trend was observed in the rate of delayed complications that affected 72.1% of the metal-acrylic prostheses and 51.6% of the zirconia, and it was found that a zirconia structure reduced the risk for delayed complications up to 59% when compared with metal-acrylic prosthesis, OR = 0.41 (*P* = .074) (Table 2).

Minor and Major Complications, and Catastrophic Failure

Among both investigated groups, minor complications were the most prominent (67.6%). Single tooth fracture/dislodgment in the metal-acrylic group (94 times in 22 prostheses) and single tooth chipping/fracture in the zirconia prostheses (36 times in 9 prostheses) were the most common events. Next were major complications (35.1%), with multiple teeth fracture (requiring laboratory processing) as the most prevalent in both groups (40 times in 17 metal-acrylic,

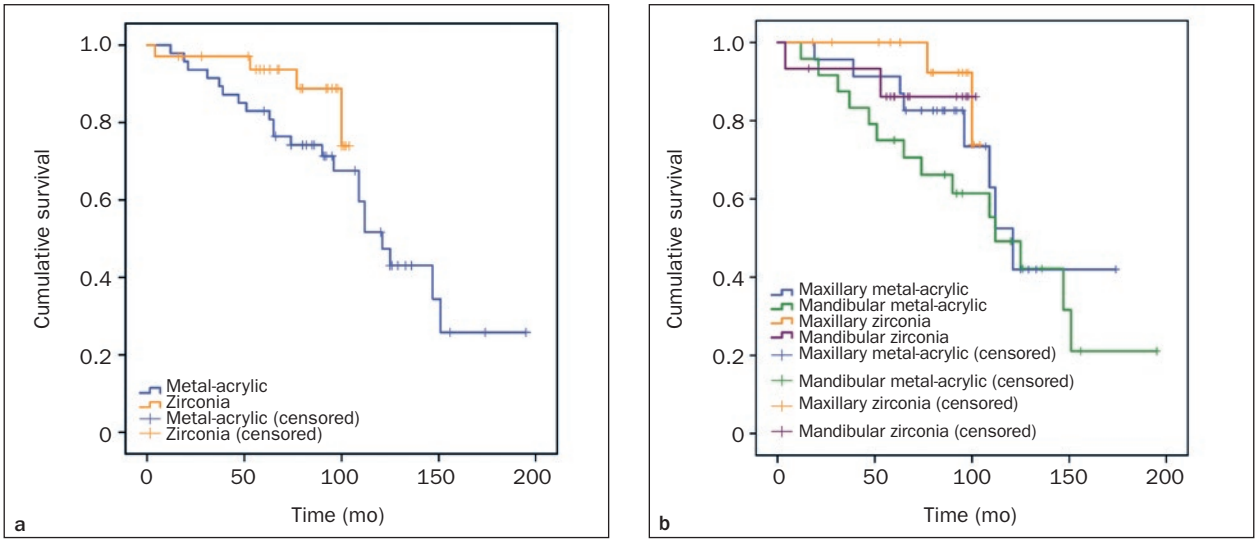

Fig 1 Survival plots based on the Kaplan-Meier analysis. *(a)* Overall survival of metal-acrylic and zirconia fixed implant prostheses. *(b)* Survival analysis based on different arches for both metal-acrylic, and zirconia fixed implant prostheses.

and 17 times in 4 zirconia fixed implant prostheses). Lastly, catastrophic failures were observed two times in both groups ($P > .05$). The number of prostheses affected by minor complications was slightly higher in the metal-acrylic group than the zirconia group (72.1% and 61.3%, $P = .329$), exhibiting a mean value of 3.4 vs 1.7 minor complications per case, respectively ($P = .05$). Major complications were more prominent in the metal-acrylic group as well (41.9% vs 25.8%). However, after adjusting for the different follow-ups, this difference lacked statistical significance ($P = .15$). An overview of all complications and implant failures that occurred with respect to time is displayed in Table A3 in Appendix 2.

Prosthesis Survival Rate

The estimated cumulative survival rate of zirconia and metal-acrylic prostheses at 5 years was 93.7% ± 5.5% vs 83.0% ± 11.1%, respectively. At 8 years, the estimated rate for zirconia prostheses was 88% ± 8.8% vs 67.6% ± 14.8% for the metal-acrylic hybrids (which became 51.7% ± 12.1% at the 10-year follow-up) (Fig 1a). The Log Rank (Mantel-Cox) test confirmed the nonequality in survival distribution among the fixed implant prosthesis groups ($P = .046$). Moreover, rehabilitation on maxillary arches presented with higher survival rates for both types of prostheses (mean survival time of 125.7 months [95% CI (101.82, 149.74)]) for maxillary metal-acrylic vs 113.5 months (95% CI [86.79, 140.23]) for mandibular metal-acrylic hybrids; and mean survival time of 101.185 (95% CI [97.175, 105.195]) for maxillary vs 91.94 (95% CI [78.33, 105.195]) for mandibular zirconia fixed implant prostheses (Fig 1b).

Biologic Complications

Prosthesis-Induced Biologic Complications. Prevalence of biologic complications related to the prosthesis was relatively similar between both groups ($P > .05$). In treated arches with metal-acrylic fixed implant prostheses, there were four instances of ulceration, two cases of epulis fissuratum (caused by instability and looseness of the prosthesis), four reports of pain and soreness associated with the acrylic, one case in which the denture had been causing obstruction of the Stenson's duct and needed refabrication, and a single event of candidiasis (treated with antifungal medication). In the zirconia group, two patients presented with oral candidiasis (treated with antifungal medications and steroids), one hyperplasia, and one case of gingival overgrowth (treated with gingivectomy).

Peri-implantitis

The prevalence of peri-implantitis for both study groups is presented in detail (Appendix 5). A GEE, adjusted for smoking, history of periodontitis, and follow-up time demonstrated a similar incidence of peri-implantitis within both groups per patient ($P = .5$) and per implant ($P = .9$). However, despite the prosthetic restoration, an implant placed in a patient with a history of periodontal disease increased the risk of peri-implantitis up to four times compared with an implant placed in a periodontally healthy patient (OR = 4.10, $P = .003$).

Implant Failure

At the patient level, 23.3% of subjects experienced implant failure in the metal-acrylic and 19.4% in the zirconia group ($P = .68$). When adjusted for smoking,

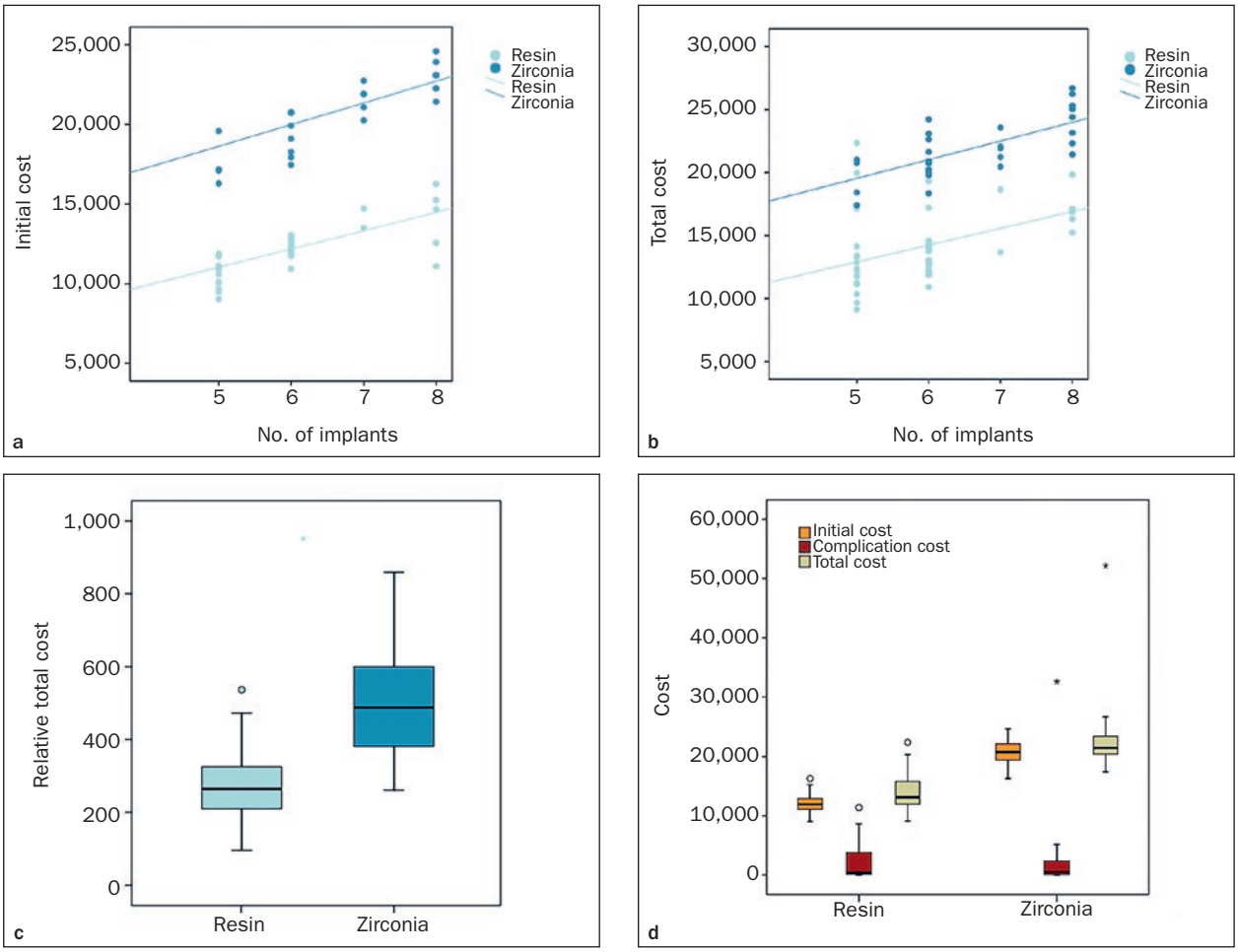

Fig 2 Projection of cost expenditure through the overall follow-up time for metal-acrylic and zirconia prostheses. *(a)* Initial cost based on the number of implants utilized to support the framework. *(b)* The total computed cost according to the number of implants. *(c)* The relative total cost per group. *(d)* An overview of all computed costs for each restoration.

history of periodontitis, and follow-up, no statistical differences could be seen between groups ($P = .19$). At the implant level, no statistically significant differences were observed between the groups after adjusting for possible confounding factors ($P = .26$). Nevertheless, it was found that an implant placed in a patient with a history of periodontitis multiplies the risk of failure by 4.3 times (OR = 4.37, $P = .01$).

Cost Analyses

Regression analyses illustrated that for the same number of implants, a zirconia prosthesis required a significantly higher initial cost, on average an additional $7,829 compared with the metal-acrylic fixed implant prosthesis ($P < .001$). Additionally, when adjusted for the longer follow-up time in metal-acrylic hybrids, there were no differences in the average cost of complications in patients treated with a metal-acrylic or zirconia prosthesis ($P = .319$).

The total cost is affected by this initial cost difference, which on average was approximately $14,000 for the metal-acrylic hybrid group, and approximately $22,000 for the zirconia group ($P < .001$). Lastly, regression analysis concluded that the average cost per single implant, per every year of follow-up, was $292.3 ± $139.2 in the metal-acrylic, and $485.2 ± $141.9 in the zirconia group ($P < .01$) (Fig 2). Details regarding the initial cost for the prostheses in each group, the expenses associated with management of the complications, and the total costs are presented in Table A4 of Appendix 2.

DISCUSSION

The CAD/CAM-fabricated zirconia frameworks were introduced to overcome the mechanical drawbacks of earlier all-ceramic systems.[31–35] The increasing demand

for metal-free restorations with enhanced translucency has led to recent developments of biocompatible ceramics. These ceramics, while slowing the process of wear (typical of metal-acrylic prostheses), provide esthetic advantages to the opaque appearance of the absolute monolithic zirconia. The aim of the present study was, therefore, to retrospectively evaluate the overall characteristics, complications, and survival rate of the one-piece milled zirconia framework bars with ceramic restorations, and compare them with the traditional metal-acrylic hybrids.[10,36,37]

Since a definitive consensus in the literature regarding description of technical events has not been established yet,[38] the authors of the present study proposed their own categories to facilitate the comparison between the metal-acrylic and zirconia fixed implant prostheses. Minor complications were the most frequently recorded event among both prosthesis groups, presenting mainly as tooth chipping/fracture in both the metal-acrylic and zirconia prostheses at rates of 51% and 29%, respectively. Papaspyridakos and Lal, in a 4-year retrospective case series, stated that porcelain fracture/chipping was the most frequent complication in zirconia fixed implant prostheses, yielding a 31% ceramic chipping rate.[25] Moreover, results from a 3-year prospective study on mandibular cement-retained implant-supported zirconia prostheses also reported a high chipping rate of 34%.[39] It is worth mentioning that the longer follow-up of zirconia fixed implant prostheses in the present study, and the similar but not identical design of the prosthesis, may inhibit an exact comparison of all the findings of the present study to that of other publications. Furthermore, it should be noted that the ceramic thickness used for fabrication of the included prostheses was 1 mm in the anterior region and at least 1.5 mm in the posterior areas, which had been due to the lack of proprioception around the implants and the inclination toward providing increased bulk, aiming to reduce ceramic fractures.

Regarding metal-acrylic fixed implant prostheses, it was noticed in the present study that 22 metal-acrylic hybrid prostheses (51%) were affected by fracture of denture teeth in an average period of almost 10 years. This high incidence can also be observed in another study, where Purcell and coworkers reported 28 fractures of denture teeth in 46 metal-acrylic hybrids in an average recall time of 7.9 years.[14] In addition, Göthberg and coworkers concluded that in 3 years, approximately 23% of patients with hybrid prostheses experienced fracture of the resin matrix, including the acrylic teeth.[40] Interestingly, different authors possess different perceptions concerning tooth fracture episodes, as many studies have acknowledged tooth fracture and tooth wear as major complications for the metal-acrylic hybrids,[40,41] while others have dismissed them as easily fixable and noncatastrophic.[42,43]

In the comparison between the metal-acrylic and zirconia fixed implant prostheses, a higher trend was observed for complications in the metal-acrylic group, despite lacking statistical significance. Furthermore, a direct correlation between the follow-up time and complication rates was also found. A recent retrospective analysis directly comparing four types of full-arch restorations (including zirconia fixed implant prostheses, porcelain-veneered zirconia, metal-acrylic hybrids, and retrievable crowns on titanium frameworks) found that chipping and fracturing of teeth was the most-reported complication among all treatment groups, after posterior wear of the prostheses.[44] Additionally, similar to the observations of the present study, metal-acrylic hybrids experienced significantly greater complications than zirconia prostheses but less than porcelain-veneered zirconia and retrievable crown fixed implant prostheses. The authors stated that all the complications in the retrievable crown prostheses were associated with the porcelain-fused-to-metal restorations and that the relatively high complication rate (50%) associated with porcelain-veneered zirconia prostheses may have stemmed from the patients' and providers' desire in the selection of laminated zirconia due to its esthetic appeal. It is worth noting that in the present study, the prostheses consisted of individual ceramic crowns that, when compared with that of the previous study, presented with fewer complications in addition to a longer follow-up time. Additionally, Maló and colleagues had emphasized a significant increase in complication rates from 5 to 10 years in implant-supported fixed prostheses.[45]

The importance of the opposing dentition in regard to prosthetic complications and failures has been previously addressed in many studies.[14,45–47] A correlation with metal-ceramic and zirconia prostheses in the opposing arch and increased prosthetic complications has been found.[45] Conversely, a trend toward lower prosthetic complications with opposing conventional metal-acrylic hybrids has also been demonstrated.[46] In the present study, the majority of the zirconia fixed implant prostheses were opposed by zirconia-based restorations (90.3%), and most of the metal-acrylic hybrids were opposed by acrylic-based restorations (67.1%). However, it was observed that the metal-acrylic prostheses encountered more complications compared with the zirconia group, which were mostly in occlusion with zirconia fixed implant prostheses.

An emerging concern in the evolving field of dental implants is the prevalence of peri-implantitis. The present study failed to find a significant difference between either prosthetic type when confounding variables (difference in follow-up time, number of smokers,

patients with past history of periodontitis) were controlled. Nevertheless, a history of periodontitis was recognized as an important prognostic factor for future peri-implantitis and implant failure, increasing the risk of peri-implantitis four times compared with a periodontally healthy patient. This matches the results of Karoussis et al, who observed that patients with a history of periodontitis are more at risk of being affected by peri-implant mucositis and peri-implantitis.[48] Thus, a careful assessment of the patients' periodontal status is imperative before planning an implant-supported prosthesis, and patients should be informed individually of the risk of peri-implantitis and implant failure in case of a previous history of periodontitis.

A crucial element of this project was assessing the long-term survival of each treatment modality. The survival criteria implemented in the present study reflect the functionality of the prosthesis, without the need for substitution. In the zirconia group, two events of framework fracture, and two catastrophic failures, resulted in failure of the prostheses. Higher survival rates can be seen in the literature; Papaspyridakos and Lal reported 100% survival of zirconia prostheses in function,[25] and Kolgeci et al, in a case series, reported a survival rate of 96.4% at 5 years.[49] A shorter follow-up (4 years) in the former,[25] and a combination of different fixed prostheses (single, partial, full-arch dentures) in the latter,[49] may have contributed to slightly higher rates. Conversely, a 12-month prospective clinical study that enrolled 17 patients reported a survival rate of 88%.[20] In the metal-acrylic group of the present study, wear of the prostheses was the main contributor of prosthetic failure, followed by framework fracture and a few cases of multiple denture teeth fractures that significantly reduced the survival rates (83.0% ± 11.1% at 5 years, and 51.7% ± 12.1% at 10 years). In a retrospective study, Priest et al stated that the replacement of the hybrid dentures in a private practice was a frequent event due to the common wear.[15] However, data gathered retrospectively from another private practice led to a higher survival rate of 91% at 5 years for metal-acrylic hybrids.[50]

One of the virtues of having an extensive follow-up for both the metal-acrylic and zirconia fixed implant prostheses is the possibility to compare the expenses associated with their long-term function. To the best of the authors' knowledge, there are no other studies comparing the cost of both treatments; therefore, a direct comparison to the literature is not possible. However, it is apparent that using individualized porcelain crowns over milled zirconia frameworks is associated with higher fees than conventional metal-acrylic prostheses. As demonstrated by the results, an additional fee of $7,829 accompanied the zirconia treatment protocol used in the present study. This initial added cost (due to the nature of the materials, CAD/CAM technology, increased laboratory fees) is the determinant factor for the overall more expensive price of the zirconia fixed implant prosthesis. As shown in the results of the present study, the expenses associated with the maintenance of prostheses and fees toward complication handling are relatively similar among both treatment groups ($2,041 vs $2,185). This lack of a price difference for treating complications, despite the higher costs related to zirconia and ceramic materials, can be due to the documented decrease in delayed complications (up to 59%) and a significant decline in the risk of prosthetic failure that accompanies the zirconia frameworks. Therefore, the main disadvantage of the zirconia prostheses compared with the metal-acrylic hybrids (the higher cost of the milled zirconium prosthesis) is ultimately minimized by the lower tendency of complications.

The limitations of this study pertain to the different follow-up time (approximately 2 years) and sample size among the metal-acrylic and zirconia groups, which can both be attributed to the retrospective nature of the research. To the authors' knowledge, studies assessing the long-term (> 5 years) follow-up of milled zirconia prostheses with single crowns are rare in the literature, and this is the first study comparing and reporting their cost-effectiveness with that of the more conventional metal-acrylic hybrids. With this in mind, it is acknowledged that the esthetic appearance, the occlusal scheme, and the subjective patient-reported outcomes are important factors that could not be analyzed.

The zirconia prostheses seem promising, but not without technical complications. Indeed, enhanced predictability of this treatment may benefit from the continuing advancements in digital workflow and design. While the initial cost of the metal-acrylic prostheses is significantly lower than the zirconia, due to fewer overall complications for the zirconia prostheses, the overall maintenance of the prostheses and the treatment of those complications do not vary greatly among the two protocols. The metal-acrylic hybrids seem cost-effective; however, the survival of these hybrids significantly declines after 5 years in function, and care should be taken in treating patients with a past history of periodontitis. Additional comparative clinical studies are needed to verify the results of the present study.

CONCLUSIONS

Within the limitations, zirconia fixed implant prostheses presented higher initial costs than metal-acrylic hybrids, however, with satisfactory outcomes, reduction of overall complications, and superior survival rates.

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Appendix 1 STROBE Checklist

	Item No	Recommendation
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract – page 395 (b) Provide in the abstract an informative and balanced summary of what was done and what was found – page 395
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported – pages 395–396
Objectives	3	State specific objectives, including any prespecified hypotheses – page 396
Methods		
Study design	4	Present key elements of study design early in the paper – page 396
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection – pages 396–397
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants – pages 396–398
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable – pages 397–398
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group – for both groups all complication assessments, and cost analyses are described in pages 397–398
Bias	9	Describe any efforts to address potential sources of bias – A thorough search of all implant treatment cases was carried out and reviewed against the criteria by two reviewers (page 396)
Study size	10	Explain how the study size was arrived at – page 396
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why – pages 397–398
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding – page 398 (b) Describe any methods used to examine subgroups and interactions – page 398 (c) Explain how missing data were addressed – no missing data were encountered (d) If applicable, describe analytical methods taking account of sampling strategy – pages 397–398 (e) Describe any sensitivity analyses – page 398
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed – page 398 (b) Give reasons for non-participation at each stage – page 398 (c) Consider use of a flow diagram – due to the numerous figures, the inclusion of patients was descriptively reported
Descriptive data	14*	(a) Give characteristics of study participants (eg, demographic, clinical, social) and information on exposures and potential confounders – page 398 and Table 1 (b) Indicate number of participants, with missing data for each variable of interest –page 398 and Table 1
Outcome data	15*	Report numbers of outcome events or summary measures – pages 399–401
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included – pages 399–401 (b) Report category boundaries when continuous variables were categorized – pages 399–400 (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period – not applicable
Other analyses	17	Report other analyses done—eg, analyses of subgroups and interactions, and sensitivity analyses – pages 399–401
Discussion		
Key results	18	Summarize key results with reference to study objectives – pages 401–403
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias – page 403
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence – page 403
Generalizability	21	Discuss the generalizability (external validity) of the study results – page 403
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based – page 404

*Give information separately for exposed and unexposed groups.
Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

APPENDIX 2

Surgical Procedures

In case of a computer-guided surgery, digital 3D diagnostic and treatment planning were performed by the company software (Nobel Biocare), which defined the implant position and size by combining the future 3D teeth setup and the patient's anatomy. Treatment planning involved cone beam computed tomography (CBCT) (3DX Accuitomo FPD; J Morita Mfg) or CT scans of both the patient and the prosthetic-driven radiographic guide following the double-scan protocol: a first scan of the patient wearing the radiographic guide prepared after the diagnostic tooth set-up, and a second scan only of the template. Next, both scans were superimposed for optimal implant positioning. The software planning data were then sent to the manufacturer (Nobel Biocare), where a surgical template with hollow metallic sleeves was designed and produced to guide the implants accordingly. When immediate loading was necessary, full acrylic resin screw-retained provisional prostheses were prefabricated based on the surgical guide, and the model obtained from the surgical templates was placed intraorally in the proper position and fixed with anchorage pins. After correct placement and stabilization of the surgical template, flapless implant surgery and fully guided implant placement were performed following the drilling protocol.

In cases of non–computer-guided implant placement, the rehabilitation was first planned on panoramic radiographs or 3D (CBCT or CT) diagnostic imaging. Consequently, surgical guides were constructed from the diagnostic tooth set-up and cast model analysis using a light-polymerized composite material, where drill blanks placed in the prosthodontically driven implant position were set to assist the free-hand surgery. After a full-thickness flap reflection for sufficient exposure and access to bone (and a vertical incision if necessitated), the conventional drilling sequence proceeded according to manufacturer instruction. A variety of implant systems (NobelSpeedy groovy, NobelActive, and NobelReplace Tapered Groovy implant, Nobel Biocare; Zimmer TSV, Zimmer; Brånemark Mark III and IV, Biohorizons) were utilized in this group. Guided bone regeneration (GBR) was performed simultaneously, when necessary, using allograft particulate bone (Puros Zimmer) and an absorbable collagen membrane (Bio-Gide, Geistlich Pharma) to repair bone defects and augment horizontal bone volume. Some of the patients were restored with a fixed provisional, immediately loaded prosthesis, while others went for early or delayed loading depending on the primary stability.

Metal-Acrylic Prosthesis Group

After healing, all implants were connected with resin (Autopolymerizing acrylic resin, ALIKE; GC America, ALSIP), and impressions were taken using the implant level-open-tray technique. A verification jig was used to determine the accuracy of the impression and to record the initial jaw relationships. The cast was mounted on a non-arcon semi-adjustable articulator, using an arbitrary facebow and inter-occlusal records. Castable abutments were used, and the wax-up for framework fabrication was done. After casting, the fitting of the framework was carried out using a disclosing media (Kerr's Disclosing Wax, Kerr; and Occlude, Pascal) in order to seat the framework passively. Resin denture teeth were waxed to the metal framework, and a final wax try-in was carried out to check the esthetic and phonetic aspects along with maxilla-mandibular relationships. Prior to delivery, the prosthesis was polished after the flasking procedure, and the occlusal contacts were refined through a clinical remount (Appendix 3).

Zirconia Prosthesis Group

After healing, custom-made abutments were placed, and a monolithic zirconia prosthesis was virtually planned using the Procera Implant Bridge system (Nobel Biocare). The prosthesis was designed to load single ceramic crowns (IPS e.max ZirPress, Ivoclar Vivadent) to establish a highly esthetic prosthesis (with minimal ceramic thickness of 1 mm in the anterior and 1.5 mm in the posterior regions). A Nobel Procera Zirconia Implant framework was milled by the manufacturer. To mimic the missing gingival tissues, light cured resin material was applied according to the position of the crowns (Appendix 4a). The prosthesis was screwed to the implants, and full ceramic crowns were designed to fit on their relative abutments on the Procera Implant Bridge. All crowns were cemented using a self-adhesive resin cement (Ivoclar Vivadent) (Appendix 4b), and occlusal adjustments were made to achieve a harmonious occlusion.

Cost Analysis

The main goal was obtaining a more comprehensive perception of cost–effectiveness and to compare both approaches. The average cost for all clinical procedures was determined throughout the follow-up period, which was then used to standardize the fees among both groups. The costs were categorized into the following:

- Initial cost: That included all fees for implant placement and prosthetic rehabilitation. Within the initial cost, every treatment fee, such as preliminary consultation appointments, use of any diagnostic aids, laboratory fees, preparations, and the entire cost of surgery were included.
- Cost for complication management: The expenses associated with complications related to implant and prosthesis management. Included any fee related to follow-up maintenance, as well as management of any biologic or prosthetic complication pertaining to any of the components.
- Total cost: The sum of initial cost and cost for complication management

The cost of all treatments associated with initial placement and management procedures were predetermined based on an average of their individual costs every year since 1990, at the University of Michigan, School of Dentistry to formulate a price list. Next, all the procedures pertaining to each patient file were scanned and recorded by one study investigator (H.A.). Wherever doubt arose, an expert in the matter (H.L.W.) was referred to. With these records, the cost of performed treatments and managements for each patient was computed into the aforementioned categories. Thus, whether or not a patient had actually paid for the provided treatments, the actual cost was presumed within the particular patient's cost of treatment.

The average cost of each procedure was calculated as follows:

$$\text{Cost} = \frac{\text{Cost}_1 + \text{Cost}_2 + \text{Cost}_3 + \text{Cost}_4 + \ldots + \text{Cost}_n}{n}$$

Cost_x = Total Procedure Expenditure at a Given Year (year_x)
n = Total number of Cost_x events for a prosthesis

Table A1 Participant Data and Descriptive Analysis of Technical Complications (Metal-Acrylic Fixed Implant Prosthesis)

Participants			Implants						
N	Sex	Age (y)	N	Immediate vs delayed	Arch	Opposing	Follow-up duration (month)	Implant failure	Screw loosening
1	F	63	8	Delayed	Maxilla	Teeth/Crowns	146		
2	F	58	6	Delayed	Maxilla	Teeth/Implants	129		
3	M	61	5	Delayed	Mandible	Denture	156		
4	F	53	5	Delayed	Mandible	MA hybrid	175		
5	F	58	6	Delayed	Maxilla	RPD	82		
6	F	56	6	Immediate	Mandible	Teeth/Implants	137	6	
7	F	61	5	Delayed	Mandible	MA hybrid	174		
8	F	51	5	Delayed	Maxilla	MA hybrid	86	5	
9	F	51	5	Delayed	Mandible	MA hybrid	86	5	
10	F	52	8	Delayed	Maxilla	Teeth/Implants	95		
11	M	80	5	Delayed	Mandible	MA hybrid	93	5	1
12	F	62	6	Immediate	Mandible	Denture	154		
13	F	71	6	Delayed	Maxilla	MA hybrid	66		
14	F	44	5	Delayed	Mandible	Denture	284		2
15	M	22	7	Delayed	Maxilla	MA hybrid	125		
16	M	22	6	Delayed	Mandible	MA hybrid	126		
17	M	43	5	Delayed	Mandible	MA hybrid	242		
18	M	45	8	Delayed	Maxilla	MA hybrid	174	6	
19	M	49	5	Delayed	Mandible	MA hybrid	116		
20	M	49	6	Delayed	Maxilla	MA hybrid	174		
21	M	59	6	Delayed	Maxilla	Teeth/Crowns	73		
22	M	79	5	Delayed	Mandible	Denture	60		
23	M	78	5	Delayed	Mandible	Crowns	119		
24	M	48	5	Delayed	Mandible	Denture	92		
25	M	81	5	Delayed	Mandible	Imp Over	92		
26	F	63	8	Delayed	Maxilla	Teeth/Crowns	80		
27	M	64	8	Immediate	Maxilla	MA hybrid	92		
28	M	60	6	Immediate	Mandible	MA hybrid	136		
29	M	69	6	Delayed	Maxilla	MA hybrid	85		
30	M	71	5	Delayed	Mandible	MA hybrid	67	1	
31	F	78	6	Delayed	Maxilla	Teeth/Crowns	98	1	
32	F	46	5	Delayed	Mandible	Teeth	124		5

MA hybrids = metal-acrylic hybrid prosthesis; RPD = removable partial denture; Imp Over = implant overdenture.

Technical complications						
Abutment fracture	Incidence of single tooth fracture/dislodgment (chairside repair)	Incidence of multiple teeth fracture and/or labwork required	Acrylic fracture	Framework fracture	Prosthesis replacement	Catastrophic failure
	6		2	1	1	
	7	2				
			3			
					1	
					1	
	4	2		1	1	
	2					
	2				1	1
					2	
	2					
2					1	
	1	1	2			
	2					
	6	8		3	2	
	5	1	1		2	
	8	2			2	
					1	
			2		1	
	4	1				
	5	1	2			
	4	4				
2		2	1		1	
	5	1	2		1	
					1	1

Table A1 Participant Data and Descriptive Analysis of Technical Complications (Metal-Acrylic Fixed Implant Prosthesis)

Participants			Implants						
N	Sex	Age (y)	N	Immediate vs delayed	Arch	Opposing	Follow-up duration (month)	Implant failure	Screw loosening
33	F	60	5	Delayed	Mandible	Denture	120		1
34	M	65	6	Delayed	Maxilla	Teeth/Crowns	107	1	
35	F	62	6	Delayed	Maxilla	Teeth/Crowns	133		
36	M	59	6	Immediate	Mandible	MA hybrid	126		
37	M	60	6	Immediate	Maxilla	MA hybrid	120		
38	F	51	6	Delayed	Maxilla	MA hybrid	74		
39	M	57	5	Delayed	Mandible	MA hybrid	95		
40	M	57	6	Delayed	Maxilla	MA hybrid	91	1	
41	F	62	6	Delayed	Maxilla	Crowns	85		
42	M	83	5	Delayed	Maxilla	Teeth/Implants	60		
43	F	65	7	Delayed	Maxilla	MA hybrid	125	1	
	20F 23M	58.7	252		22 Maxilla 21 Mandible		118 ± 45.8		9

MA hybrids = metal-acrylic hybrid prosthesis; RPD = removable partial denture; Imp Over = implant overdenture.

Table A2 Participant Data and Descriptive Analysis of Technical Complications (Zirconia Fixed Implant Prosthesis)

Participants			Implants					
N	Sex	Age (y)	N	Immediate vs delayed	Arch	Opposing	Follow-up duration (mo)	Implant failure
1	F	53	7	Delayed	Maxilla	Teeth/Implants	92	
2	M	48	6	Delayed	Maxilla	IZFP	67	
3	M	48	5	Delayed	Mandible	IZFP	69	1
4	M	33	8	Delayed	Maxilla	IZFP	60	
5	M	33	6	Delayed	Mandible	IZFP	60	
6	M	81	6	Delayed	Maxilla	Teeth	68	
7	M	74	6	Delayed	Maxilla	IZFP	58	
8	M	74	5	Delayed	Mandible	IZFP	58	1
9	F	58	7	Delayed	Maxilla	Crowns/Implants	97	1
10	F	54	8	Delayed	Maxilla	Teeth/Crowns	123	
11	F	63	8	Delayed	Maxilla	IZFP	104	
12	F	63	6	Delayed	Mandible	IZFP	104	
13	M	80	6	Delayed	Maxilla	IZFP	132	
14	F	50	5	Delayed	Mandible	IZFP	101	4
15	F	65	5	Delayed	Mandible	IZFP	123	
16	M	55	6	Delayed	Maxilla	IZFP	99	
17	M	55	5	Delayed	Mandible	IZFP	98	
18	M	64	8	Delayed	Maxilla	IZFP	60	
19	M	50	6	Delayed	Maxilla	IZFP	80	
20	M	50	5	Delayed	Mandible	IZFP	79	
21	M	71	8	Delayed	Maxilla	IZFP	132	
22	M	71	7	Delayed	Mandible	IZFP	119	7
23	F	78	5	Delayed	Mandible	IZFP	116	
24	F	69	7	Delayed	Maxilla	IZFP	63	
25	F	69	8	Delayed	Mandible	IZFP	63	
26	M	56	6	Delayed	Maxilla	IZFP	105	

IZFP = implant-supported zirconia fixed prosthesis.

Technical complications						
Abutment fracture	Incidence of single tooth fracture/dislodgment (chairside repair)	Incidence of multiple teeth fracture and/or labwork required	Acrylic fracture	Framework fracture	Prosthesis replacement	Catastrophic failure
	3	4				
	2					
		1			1	
	3				1	
	5	1				
	8	2				
	2	3	1		1	
1	8	5	1		1	
5	94	41	17	5	23	2

Technical complications						
Screw loosening	Re-cementation	Incidence of single tooth chipping/fracture chairside repair)	Incidence of multiple teeth fracture and/or labwork required	Zirconia bar fracture	Prosthesis replacement	Catastrophic failure
			1			
				1	1	
		6				
				1	1	
1						
1						
	4					
	2	5	1			
		1				
	1	1				
	1	7				
		2	2			
	1			1		
1						
	1					1
1						
	1	1	1			

Table A2 Participant Data and Descriptive Analysis of Technical Complications (Zirconia Fixed Implant Prosthesis)

Participants			Implants					
N	Sex	Age (y)	N	Immediate vs delayed	Arch	Opposing	Follow-up duration (mo)	Implant failure
27	M	52	8	Delayed	Maxilla	IZFP	93	
28	M	52	7	Delayed	Mandible	IZFP	93	
29	F	78	8	Delayed	Maxilla	IZFP	112	
30	M	52	6	Delayed	Maxilla	IZFP	95	5
31	M	52	6	Delayed	Mandible	IZFP	95	
	11F 20 M	59.7	200		18 Maxilla 13 Mandible		90.9 ± 23.49	

IZFP = implant-supported zirconia fixed prosthesis.

Table A3 Incidence of Complications Per Year for Metal-Acrylic and Zirconia Fixed Implant Prostheses Throughout The Follow-up

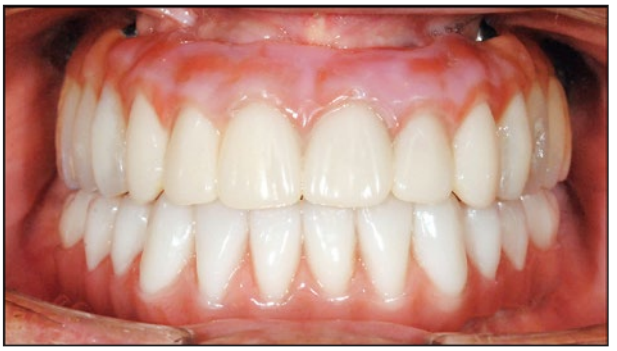
Type of prosthesis	Incidence of events	Time (mo)							Total
		0-12	12-24	24-36	36-48	48-60	60-120	120+	
Metal-acrylic	Screw loosening						5	2	7
	Abutment fracture			1			1	1	3
	Single tooth fracture/ dislodgment	11	8	12	14	7	29	12	93
	Multiple teeth fracture/ dislodgment	1	3	5	2	7	15	5	38
	Acrylic fracture	3	3	2	1	2	3	4	18
	Framework fracture		2		2	3	1	1	9
	Prosthesis replacement			3	3		12	4	22
	Implant failure	4		2		1	11		18
	Catastrophic failure	1					1		2
	Number of prostheses followed	46	46	46	46	46	41	20	
Zirconia	Screw loosening	2			1	1			3
	Re-cementation	2	2	4	3		3		14
	Single tooth ceramic chipping	5	3	7	3	4	5		27
	Multiple tooth ceramic chipping	5	3	2	3	2			15
	Prosthesis replacement	1				1	1		3
	Bar fracture	2					1		3
	Implant loss	1				4	1		6
	Catastrophic failure						2		2
	Number of prostheses followed	31	31	31	29	31	26		

Technical complications						
Screw loosening	Re-cementation	Incidence of single tooth chipping/fracture chairside repair)	Incidence of multiple teeth fracture and/or labwork required	Zirconia bar fracture	Prosthesis replacement	Catastrophic failure
		12	1			
	1	1	3		1	1
4	12	36	9	3	4	2

Table A4 Associated Costs with the Zirconia and the Metal-Acrylic Prostheses

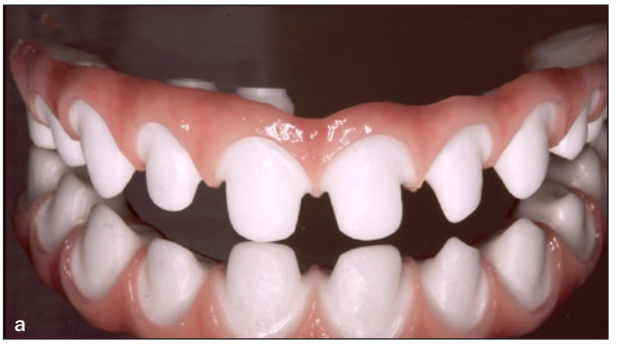
		Prosthesis group		
		Resin	Zirconia	Total
Initial cost	N	43	31	74
	Mean	12,023.8	20,518.2	15,582.2
	Standard deviation	1,480.2	2,173.6	4,583.3
	Minimum	9,040.0	16,286.0	9,040.0
	Maximum	16,264.0	24,586.0	24,586.0
	Median	11,889.0	20,751.0	13,026.0
	Sum	517,023.0	636,063.0	1,153,086.0
Complication cost	N	43	31	74
	Mean	2,041.4	2,185.4	2,101.7
	Standard deviation	2,841.1	5,846.7	4,324.0
	Minimum	0.0	0.0	0.0
	Maximum	11,347.0	32,630.0	32,630.0
	Median	366.0	486.0	410.5
	Sum	87,779.0	67,747.0	155,526.0
Total cost	N	43	31	74
	Mean	14,065.2	22,703.5	17,683.9
	Standard deviation	3,126.9	5,963.5	6,217.3
	Minimum	9,133.0	17,385.0	9,133.0
	Maximum	22,356.0	52,216.0	52,216.0
	Median	13,066.0	21,431.0	17,304.5
	Sum	604,802.0	703,810.0	1,308,612.0

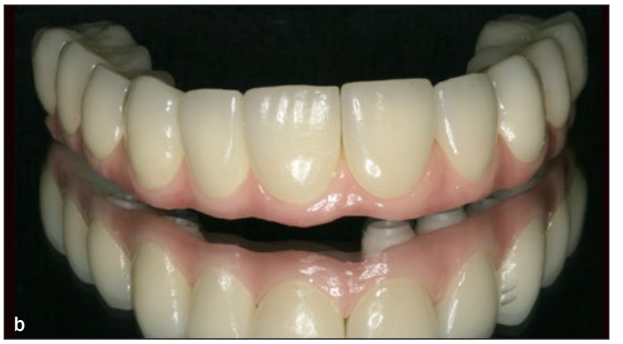
All expenses refer to standardized costs in U.S. dollars.



Appendix 3 *(Left)* Intraoral view of metal-acrylic hybrid prosthesis.

Appendix 4 *(Below) (a)* Zirconia framework. *(b)* After cementation of the crowns.





Appendix A5 Incidence of Peri-implantitis for Both Groups

	Metal-acrylic				Zirconia			
N	Arch	Follow-up duration (mo)	N of implants	N of implants with P-I	Arch	Follow-up duration (mo)	N of implants	N of implants with P-I
1	Maxilla	146	8	0	Maxilla	92	7	7
2	Maxilla	129	6	1	Maxilla	67	6	0
3	Mandible	156	5	1	Mandible	69	5	1
4	Mandible	175	5	0	Maxilla	60	8	0
5	Maxilla	82	6	2	Mandible	60	6	0
6	Mandible	137	6	4	Maxilla	68	6	1
7	Mandible	174	5	0	Maxilla	58	6	0
8	Maxilla	86	5	5	Mandible	58	5	1
9	Mandible	86	5	5	Maxilla	97	7	2
10	Maxilla	95	8	6	Maxilla	123	8	0
11	Mandible	93	5	1	Maxilla	104	8	0
12	Mandible	154	6	0	Mandible	104	6	0
13	Maxilla	66	6	0	Maxilla	132	6	2
14	Mandible	284	5	0	Mandible	101	5	5
15	Maxilla	125	7	1	Mandible	123	5	4
16	Mandible	126	6	0	Maxilla	99	6	0
17	Mandible	242	5	1	Mandible	98	5	0
18	Maxilla	174	8	0	Maxilla	60	8	3
19	Mandible	116	5	0	Maxilla	80	6	1
20	Maxilla	174	6	0	Mandible	79	5	5
21	Maxilla	73	6	3	Maxilla	132	8	1
22	Mandible	60	5	0	Mandible	119	7	7
23	Mandible	119	5	0	Mandible	116	5	0
24	Mandible	92	5	0	Maxilla	63	7	2
25	Mandible	92	5	0	Mandible	63	8	0
26	Maxilla	80	8	2	Maxilla	105	6	0
27	Maxilla	92	8	0	Maxilla	93	8	0
28	Mandible	136	6	0	Mandible	93	7	0
29	Maxilla	85	6	0	Maxilla	112	8	1
30	Mandible	67	5	0	Maxilla	95	6	5
31	Maxilla	98	6	2	Mandible	95	6	0
32	Mandible	124	5	5	18 Maxilla	90.9 ± 23.49	200	48
33	Mandible	120	5	1	13 Mandible			24%
34	Maxilla	107	6	3				
35	Maxilla	133	6	0				
36	Mandible	126	6	0				
37	Maxilla	120	6	1				
38	Maxilla	74	6	0				
39	Mandible	95	5	0				
40	Maxilla	91	6	1				
41	Maxilla	85	6	2				
42	Maxilla	60	5	0				
43	Maxilla	125	7	0				
	22 Maxilla	118 ± 45.8	252	47				
	21 Mandible			18.6%				