Milled PMMA: A Material for Long-Term Implant-Supported Fixed Complete Dental Prostheses

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Traditionally, metal-ceramics, metal-reinforced acrylics, and—more recently—full-contour or layered zirconia have been the materials of choice for definitive fixed implant-supported rehabilitations. Polymethyl methacrylate (PMMA) is commonly used in implant dentistry for the fabrication of implant-supported interim prostheses and as milled or 3D-printed prototypes. This article describes a novel protocol to prosthetically restore a completely edentulous patient following a digital workflow, with fixed, screw-retained, implant-supported prostheses fabricated from CAD/CAM milled PMMA, with no metal substructure. After a 2-year follow-up in terms of esthetics, phonetics, function, and biologic tissue response, the outcome remains functional and free of mechanical, biomechanical, or biologic complications. The aim of this article is to illustrate the feasibility of using milled PMMA as a viable definitive prosthetic material for the fixed implant rehabilitation of edentulous patients. *Int J Prosthodont 2024;37:225–231. doi: 10.11607/ijp.8420*

Clinicians currently have several options of materials and design configurations to select from when fabricating implant-supported fixed complete dentures.[1,2] It is widely accepted that any material used should provide biocompatibility, sufficient mechanical strength, wear resistance, and color stability to satisfy biologic, mechanical, and esthetic requirements.[3–5]

When considering prosthetic material selection in implant dentistry, the prominent choices include metal-ceramic, metal-acrylic, layered zirconia, and monolithic zirconia. Mechanical and technical complications have been reported as the most common adverse event when providing complete arch fixed implant-supported prostheses. However, there is significant heterogeneity in the scientific literature with regards to clinical outcomes and implications of material selection in fixed implant rehabilitation of edentulous patients.[6,7]

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Submitted December 21, 2022; accepted July 6, 2023.

Metal-ceramic restorations have been considered the gold standard in fixed prosthodontics, due to their high strength and long-term survival rates.[6,8] However, their disadvantages include their high cost, difficulty to repair, the technically sensitive nature of their workflows, and esthetic challenges in their fabrication. The esthetic appearance of these restorations is influenced by the alloy used and the thickness, color, and translucency of the layering ceramics. The most common complication is the chipping of the veneering porcelain.[9]

Metal-acrylic "hybrid"[5] restorations are among the most documented treatment protocols for restoration of an edentulous patient with a fixed implant prosthesis. Long-term evidence of these hybrids has reported simplicity in their use, reduced cost, and ease in managing complications. However, this treatment modality requires significant restorative space for the implant components, metal framework, and resin superstructure.[5] Their relatively high complication rates include denture teeth debonding, veneered acrylic fracture, and screw/abutment loosening which although often repairable, are time consuming for both patients and clinicians to resolve.[7,10]

Zirconia has emerged as an alternative metal-free framework material[11] due to its high biocompatibility, low plaque accumulation, minimal bacterial surface adhesion, high flexural strength, and reduced staining compared to acrylic resins.[12,13] Zirconia was originally used as a framework structure veneered with feldspathic porcelain. Monolithic zirconia has been introduced as an alternative to compensate for the technical complications associated with layered ceramics, especially the increased chipping rates (14.7%)[12,14] In medium-term studies, complete arch implant-supported monolithic zirconia with gingival feldspathic veneered porcelain has shown a high survival rate, lower incidence of complications, reduced laboratory costs, high durability and wear characteristics, superior fit, and the availability of digital documentation for its duplication in the future.[10,15] However, challenges have also been associated with these prostheses, including heavier weight compared to metal-acrylic prostheses, high costs, inability to repair, material's low tolerance to minor impression inaccuracies, potential debonding of titanium cylinders,[7,16] difficulty in polishing, and a protocol requiring an additional acrylic prototype try-in adjustment and approval. Long-term data with strong evidence on the clinical efficacy of complete arch implant-supported zirconia prostheses are still lacking.[17]

A wide range of polymers are commonly used for various applications in fixed, removable, and implant prosthodontics. Polymethyl methacrylate (PMMA), introduced by Walter Wright in 1937,[18] has been very well documented in the literature and is commonly used for prosthetic dental applications, including the fabrication of artificial teeth, denture bases, dentures, maxillofacial prostheses, obturators, orthodontic retainers, temporary or provisional crowns, and for the repair of dental prostheses.[19] Additional dental applications of PMMA include occlusal splints, printed or milled casts, and printed or milled prototypes.[20]

PMMA's unique properties include its low density, high biocompatibility and biostability, low weight, good esthetic behavior, cost-effectiveness, ease of manipulation, and tailorable physical and mechanical properties that make it a suitable biomaterial for these dental applications. PMMA is an amorphous polymer formed by the polymerization of the monomer methyl methacrylate. PMMA's physical and mechanical properties can be further controlled and modified by manipulating polymerization conditions and processing techniques. Thus, further improvement of the properties of PMMA (thermal properties, water sorption, solubility, impact strength, flexural strength) have been recently reported using a variety of chemical modifications and mechanical reinforcement techniques.[19]

The recent introduction of CAD/CAM technology to the field of removable prosthodontics[21] has made it possible to fabricate complete dentures from prepolymerized PMMA blocks. The number of studies on the fabrication of acrylic prostheses utilizing CAD/CAM technology has been increasing worldwide. Some superior qualities of these milled prostheses include, a lack of polymerization shrinkage during processing, very low residual monomer, and superior color stability than self-curing materials.[22] Therefore, the manufacturing of dental prostheses has evolved from heat- or self-curing PMMA to the milling of prepolymerized high-density PMMA[23,24]

Currently, prepolymerized PMMA has been used primarily for the milling of denture bases and interim prostheses. For the fixed prosthodontic restorations, PMMA has traditionally been considered as an interim restorative material used before final restoration placement. As a versatile material, it has acquired a critical role in implant dentistry for the fabrication of implant-supported interim prostheses, digitally designed and manufactured verification jigs, or 3D-printed prototypes—a key step in digital workflow for the evaluation of esthetic and functional parameters and the passive fit of all-ceramic monolithic prostheses before placement of the final rehabilitation.[25,26]

The aim of this case report is to illustrate the use of milled PMMA as an alternative definitive restorative material for implant fixed complete dental prostheses (IFCDPs) and to provide the clinical advantages of this material selection that justify its feasibility as a viable cost- and time-efficient treatment choice.

CASE REPORT DESCRIPTION

An edentulous patient presented to the clinic of Advanced Graduate Education Program in Implant Dentistry

Fig 1 *(a and b)* Digital tooth arrangement after importing the STL files of intraoral scans of the edentulous arches. *(c)* The milled-PMMA maxillary and mandibular restorations in occlusion in the articulator after pink characterization of the gingival part.

Fig 2 *(a)* Occlusal and *(b)* gingival views of the maxillary milled-PMMA prosthesis.

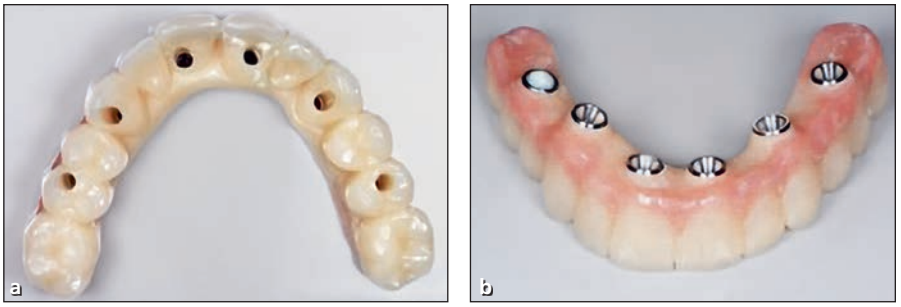
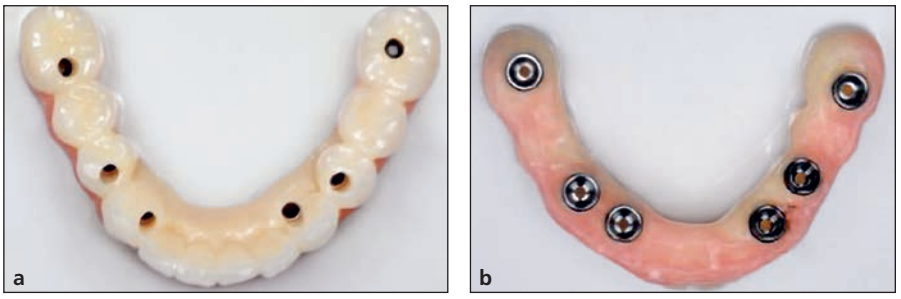


Fig 3 *(a)* Occlusal and *(b)* gingival views of the mandibular milled-PMMA prosthesis.



at the Harvard School of Dental Medicine seeking a prosthodontic consultation. The patient had previously undergone implant placement with six implants in the maxilla and six in the mandible (4.1 × 10 mm Bone Level Tapered, SLActive, Straumann) following an immediate loading protocol with a preliminary set of PMMA interim implant-supported prostheses on screw retained abutments (SRA; Screw-retained Abut, TAN—straight 0°, Ø 4.6 mm) that had been delivered prior using the pick-up technique.[27] Treatment options and financial issues were discussed with the patient, who desired to proceed with fixed implant rehabilitations.[28,29]

After the healing period of 3 months, the implant and edentulous arches were intraorally scanned (TRIOS, 3Shape) using a triple digital-scanning technique. One digital impression was made with the interim prostheses in situ including occlusal registration, one was of the implants' position after removal of the prostheses using implant impression copings (CARES Mono Scanbody, Straumann; for screw-retained abutment–abutment level, Ø 4.6 mm, PEEK/TAN), and a third was of the prostheses including the intaglio and implant prosthetic interfaces.

The resulting digital stereolithographic scan files (STL files) of the edentulous arches, interim restorations, and occlusion registration were imported into a CAD program (CARES Visual software, Straumann). A trial tooth arrangement was created based on the existing restorations with minor modifications and esthetic interventions After the diagnostic virtual tooth and gingiva setup had been completed (Figs 1a and b), a new set of maxillary and mandibular prostheses were manufactured out of premilled PMMA blocks (Temp Esthetic CAD Provisional Gradient, Harvest Dental Products) and gingival characterization was performed with pink stain (Optiglaze, GC Dental; Fig 1c). According to the manufacturer, this polymer has modulus of elasticity > 100 MPa, a bending strength > 100 Mpa, a tensile strength > 75 Mpa, and a Vickers hardness > 135. The PMMA restorations (Figs 2 and 3) were delivered to the patient (Fig 4). Esthetics and passive fit were confirmed, and minor occlusal adjustment was performed (Fig 5). The screw-access holes

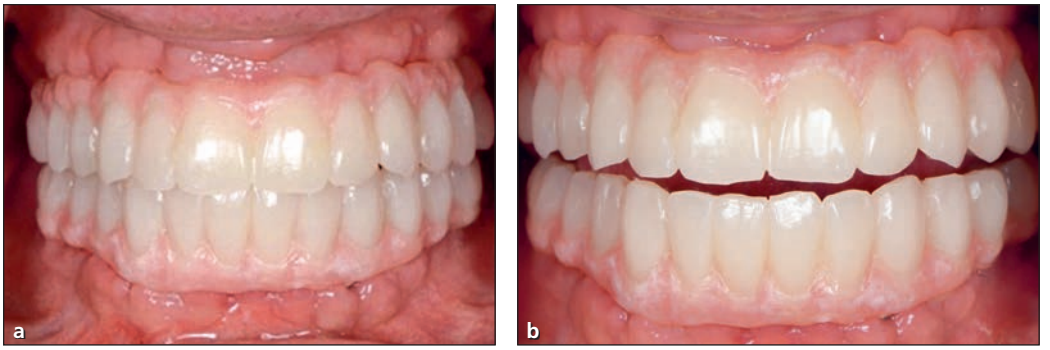


Fig 4 *(a and b)* Clinical images of the milled-PMMA maxillary and mandibular restorations intraorally after placement.

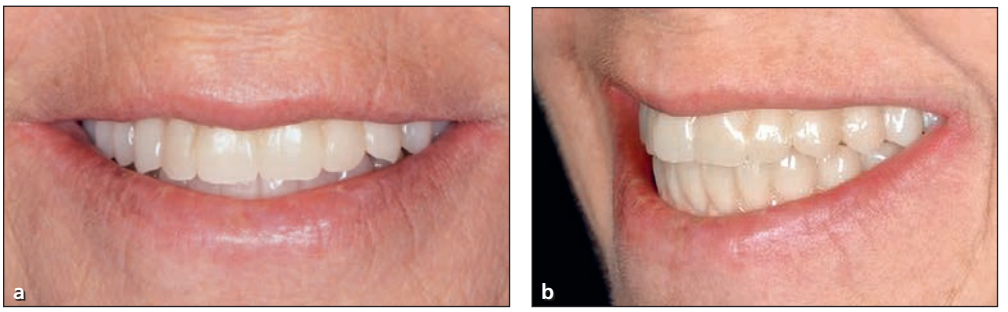


Fig 5 *(a)* Frontal and *(b)* lateral views of the patient's smile after delivery of the PMMA prostheses.

Fig 6 *(a)* Prostheses after 2-year follow-up. *(b)* Clinical and *(c)* radiographic evaluation of the esthetic and biomechanical parameters in terms of long-term success and survival rates of the PMMA prostheses.

were filled with teflon tape and composite resin. The patient was given oral hygiene instructions for cleaning around the prosthesis and dental implants.

Due to the COVID-19 pandemic, the patient remained with the interim prosthesis for 21 months. Following a 6-month follow-up recall interval, the interim PMMA prostheses was reported to be free of esthetic and mechanical complications. Hard and soft tissue peri-implant conditions remains healthy with no major biofilm deposits and no technical or biologic complications including tooth wear, chipping, fracture, or screw loosening occurred during this period. The patient reported high satisfaction with the esthetics and functional performance of the prostheses. After 2 years, a maxillary monolithic zirconia full-arch implant supported restoration with a bilateral single unit cantilever, and three mandibular segmented fixed partial dentures were fabricated and delivered as a definitive restoration. One month after placement of the zirconia prosthesis, minor chipping of the incisal edge of the left central incisor of the maxillary restoration occurred. The restoration was removed, and the interim PMMA prosthesis was reinstalled and remained in service for an additional 6 months, for a total functional time of 27 months (Fig 6). During this time, no prosthetic or biologic complications noted. Finally, following a 27-month total service time, the repaired definitive zirconia restoration was replaced. The PMMA prosthesis was stored for future use in case further complications arise with the definitive prosthesis.

DISCUSSION

The present clinical report describes the use of CAD/CAM metal-free milled PMMA in implant rehabilitation of a edentulous patient.

There are no reported clinical studies describing PMMA as a definitive treatment option. In a study of Makarov et al,[30] a digitally designed and manufactured

milled PMMA interim prosthesis fabricated without the use of a cast or model was delivered and connected to temporary cylinders attached to the implants using flowable resin and veneered with gingival composite. After 1 year of service, no prosthetic complications were recorded, the mean marginal bone loss level was 0.37 ± 0.06 mm, and the implant survival rate was 98.18%. This result anecdotally proved that CAD/CAM prefabricated-milled PMMA can be a predictable prosthetic material. Furthermore, there is only a 10-year prospective clinical study of Tartaglia et al[31] confirming the long-lasting features of both porcelain fused to zirconia (PFZ) and all-resin complete arch fixed implant-supported prostheses over a 10-year period, showing similar complication-free survival rates (29% to 30%). However, in the present study there was an increased number of mechanical complications, especially after the sixth year after the initial treatment.

In the present case report following a 27-month observation period, the prostheses demonstrated a stable clinical esthetic performance, free of mechanical or biologic complications. In contrast, 1 month after placement of the monolithic zirconia prosthesis, minor chipping of the incisal edge of the left central incisor of the maxillary restoration occurred. This incident may have occurred because of the mechanical failure of the specific material. Although significant esthetic improvement has occurred with recent monolithic zirconia types with higher yttria content and a higher cubic/tetragonal ratio, the mechanical performance may be compromised. Proper prosthetic design of recent ZrO_2 generations needs further investigation to optimize stress distribution and improve longevity, especially when dealing with thin segments of zirconia structures in high-bearing stress areas like incisal or occlusal load surfaces.[37]

The esthetic benefits of the material used in this clinical case are notable. The PMMA blocks utilized have been composed in 13 layers of natural gradients, thus allowing for multiple shades mimicking dentin translucency and offering a more natural-looking restoration and harmonious transition through cervical to incisal, resulting in highly esthetic, long-term dental prostheses.

When compared to other conventionally processed provisional materials, milled PMMA showed favorable biologic behavior—with regard to biocompatibility, cytoxicity, and human cell attachment—and is recommended to reduce exposure to residual monomer and achieve high cell attachment.[32] Recently conducted studies have found that the level of residual monomer for milled PMMA interim prosthetic restorations was minimal compared to conventional polymers.[22,33] Likewise, the study by Herráez-Galindo[34] confirmed that milled PMMA demonstrated a fibroblastic behavior similar to those of lithium disilicate, which was considered the "gold standard biocompatible material."

The mechanical traits of milled PMMA are also favorable. Additional properties of CAD/CAM milled PMMA that should be considered are their significant lighter weight compared to metal ceramics or zirconia, and the absence of the audible clicking commonly reported by patients created when opposing zirconia and ceramic prostheses collide during mastication or articulation.

Furthermore, it is also critical for any new technology to be proven cost-effective, particularly in the long term. Emerging long-term data on implant-supported fixed prosthesis treatment of edentulous arches suggest that with the likelihood of long-term implant survival, even a prosthetic therapeutic success will require maintenance and repair, while possible multiple replacements should be considered within the patient's lifetime.[2,28]

The treatment cost of the most common materials remains quite high, approximately three times higher than a PMMA prosthesis, which is relevant in the context of the patient's access to care. Metal-acrylic hybrids have been reported as a cost-effective alternative. However, the survival of these hybrids significantly declines after 5 years in function, and potential fracture, wear, or debonding of the veneering materials in hybrid prostheses should be considered a frequent complication.[10] It is the author's recommendation that clinicians should consider the cost/benefit analysis of this treatment modality, assuming the fact that even if the PMMA prosthesis may be replaced with a new prosthesis every 5 to 7 years, the cumulative treatment cost would still be extremely low, making this treatment modality affordable and appealing to more implant treatment candidates.

A significant advantage of the digital dental technology contribution is that it enables the documentation and recording of clinical cases. The digital 'blueprint' of the final prosthesis is stored and saved, allowing for the possibility of easily duplicating/replicating the existing prosthesis and replacing it in the future if necessary.[36] As a further checkpoint step, a verification jig can also be made to ensure the accuracy of fit before the restoration placement.

The consistent esthetics, biologic response, and function without complications of the milled PMMA material has altered our clinical patient-specific rationale and our future perspective in terms of the applicability of milled PMMA as a permanent material choice for implant restorations. The integration of digital technologies and the advantageous properties of milled prefabricated PMMA is capable of reducing chairside time and lowering the overall treatment time and cost of implant treatment workflow.

The clinical implications suggest that a fixed implant rehabilitation made with milled PMMA could be a milestone in implant restorative dentistry and could become a routine procedure in the near future for the benefit of both clinician and patient. Due to reduced chair-side

time, shorter overall treatment time, predictable digital diagnosis, and a predictable treatment workflow.

The limitation of the present clinical report is the lack of long-term data of scientific and clinical evidence to justify the choice of PMMA for final implant restoration. Further clinical studies assessing the clinical outcome performance of CAD/CAM metal-free PMMA compared to other restorative materials are needed to validate its feasibility as a definitive material selection for implant-supported restorations and to clarify their specific clinical indications and manufacturing protocols to optimize long-term clinical behavior.

SUMMARY

Based on the findings of the present study, use of a milled CAD/CAM PMMA prosthesis enhances several patient-centered clinical parameters and the patient's self-rated satisfaction in terms of comfort, affordable treatment cost, and time-efficiency. The advantages of this treatment modality could be summarized as the following:

- Improved esthetic properties with high transparency and the advantage of multiple layers of incisal gradient shade transition
- Enhanced mechanical properties compared to conventional processed PMMA
- Increased treatment time-effectiveness (restoration placement in three visits)
- Better cost-effectiveness
- Easy to manage the biomechanical complications; easy to duplicate and remake
- Easier maintenance and retrievability due to its screw-retention prosthetic design
- High patient satisfaction rates

Despite the limitations of the described technique in this case report including lack of long-term evidence, the clinical implication of milled PMMA as long-term restoration material provides a straightforward esthetic, time saving and cost-efficient prosthetic choice that may herald a new era in the final implant treatment of edentulous patients.

ACKNOWLEDGMENTS

The authors declare no conflict of interest.

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Literature Abstract

Are Periodontitis and Dental Caries Associated? A Systematic Review with Meta-Analyses

Aim: The epidemiological relationship between periodontitis and caries remains controversial, and evidence synthesis is currently lacking. Therefore, this systematic review was designed to answer the following PECO question: "In human adults (P), do subjects suffering from periodontitis (E) have higher presence/number of untreated carious lesions and caries experience (O) than subjects not suffering from periodontitis (C)?" Materials and Methods: Observational studies that met specific inclusion criteria established to answer to the PECO question were included. Two review authors independently searched for eligible studies, screened the titles and abstracts, carried out the full text analysis, extracted the data and performed the risk of bias assessment. In case of disagreement, a third review author took the final decision during ad hoc consensus meetings. Data synthesis was carried out through random-effects meta-analyses. Results: A total of 18 studies on 21 cohorts, involving 135,018 participants, were included. Meta-analyses showed a significant association between periodontitis and the presence of at least one tooth with either untreated carious lesions (odds ratio [OR] = 1.63; 95% confidence interval [CI]: 1.32 to 2.01; $P < .00$; I2 = 83.0%) or caries experience (decayed and filled teeth ≥ 1) (OR = 1.27; 95% CI: 1.01 to 1.59; $P = .038$; I2 = 90.0%). Moreover, subjects with periodontitis exhibited a higher number of surfaces (difference in means [MD] = 0.86; 95% CI: 0.46 to 1.27; $P < .001$; I2 = 0.0%) and teeth (MD = 0.35; 95% CI: 0.28 to 0.42; $P < .001$; I2 = 69.6%) with untreated carious lesions, as well as a higher number of teeth with caries experience (standardized difference in means [SMD] = 1.46; 95% CI: 0.15 to 2.78; $P = .029$; I2 = 98.9%) compared with those without periodontitis. Sensitivity analyses focusing on severe periodontitis as exposure mostly showed consistent results. Estimates for caries experience were only slightly attenuated in adjusted models compared with crude models. Subgroup analyses by caries location also indicated that periodontitis was associated only with root caries, while it was not with caries affecting the anatomical crown. Conclusions: Periodontitis was found to be associated with the presence and number of treated/untreated root carious lesions. Therefore, caries-specific preventive measures (eg, fluorides) should be considered for individuals with periodontitis.

Romandini P, Marruganti C, Romandini WG, Sanz M, Grandini S, Romandini M. *J Clin Periodontol* 2024;51:145–157. **References:** 50. **Reprints:** P. Romandini: pierluigi.romandini@hotmail.it—*Steven Sadowsky, USA*