THE JOURNAL OF PROSTHETIC DENTISTRY

REVIEW

Removable partial dentures: The clinical need for innovation

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ABSTRACT

Statement of problem. The number of partially dentate adults is increasing, and many patients will require replacement of missing teeth. Although current treatment options also include fixed partial dentures and implants, removable partial dentures (RPDs) can have advantages and are widely used in clinical practice. However, a significant need exists to advance materials and fabrication technologies because of the unwanted health consequences associated with current RPDs.

Purpose. The purpose of this review was to assess the current state of and future need for prosthetics such as RPDs for patients with partial edentulism, highlight areas of weakness, and outline possible solutions to issues that affect patient satisfaction and the use of RPDs.

Material and methods. The data on treatment for partial edentulism were reviewed and summarized with a focus on currently available and future RPD designs, materials, means of production, and impact on oral health. Data on patient satisfaction and compliance with RPD treatment were also reviewed to assess patient-centered care.

Results. Design, materials, ease of repair, patient education, and follow-up for RPD treatment all had a significant impact on treatment success. Almost 40% of patients no longer use their RPD within 5 years because of factors such as sociodemographics, pain, and esthetics. Research on RPD-based treatment for partial edentulism for both disease-oriented and patient-centered outcomes is lacking.

Conclusions. Future trials should evaluate new RPD materials and design technologies and include both long-term follow-up and health-related and patient-reported outcomes. Advances in materials and digital design/production along with patient education promise to further the application of RPDs and improve the quality of life for patients requiring RPDs. (J Prosthet Dent 2017;118:273-280)

The proportion of partially dentate adults is increasing, partly as a result of increased life expectancy, a rise in the number of elderly individuals within the population, and a shift from total tooth loss/total edentulism toward partial edentulism.[1-3] The prevalence of partial edentulism is already estimated at greater than 20% in some regions,[4] and the number of individuals with partial edentulism could increase to more than 200 million in the United States alone in the next 15 years.[5] In the United States, the average adult over the age of 20 has 24.9 remaining teeth, and 43.7% of all U.S. adults have had a tooth extracted. Individuals over 65 have an average of 18.9 remaining teeth, with 43.1% missing 6 or more teeth.[6,7] In the United Kingdom, the 2009 Adult Dental Health Survey found that "nearly one in five adults wore removable dentures of some description

Supported by Solvay Dental 360. This article was prepared according to the International Society for Medical Publication Professionals' "Good Publication Practice for Communication Company-Sponsored Medical Research: the GPP3 Guidelines."
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Clinical Implications

The issues raised can significantly affect the future quality of removable partial dentures by reducing health-related costs and increasing patient satisfaction and compliance.

(partial or complete)."[8] This includes the 6% of adults with complete edentulism as well as the 13% of people who use a combination of dentures and natural teeth.

Because the maintenance of oral health has improved, people are losing fewer teeth, resulting in an increased need for treatment of partial rather than complete edentulism.[2,9] Many patients require replacement of missing teeth and associated structures to enhance appearance, improve masticatory efficiency, prevent unwanted movement of teeth (overeruption/drifting), and/or improve phonetics. Because of the attendant advantages of removable prostheses on teeth and implants, the indications for treatment using removable partial dentures (RPDs) are wide and varied. For example, RPDs can be indicated to overcome financial limitations, as provisional prostheses, to facilitate hygiene access, and to overcome biomechanical and pragmatic issues associated with dental implants.[3,10] Long-span edentulous spaces (3 or more missing adjacent teeth) make it difficult to provide fixed prostheses (for example, retention/resistance form) resulting in poor prognosis.[11] In these situations, tooth-supported RPDs or implants (using fixed or removable solutions) provide alternative long-term solutions. RPDs are also the best practice therapy for many clinical scenarios, such as replacing lost hard and soft tissues, that result in a need for esthetic support of the orofacial structures, transitional prostheses for the failing dentition, and long edentulous spans.[3,10]

Given the correlation between edentulism (complete or partial) and lower socioeconomic status,[12,13] RPDs will likely remain an important treatment option compared with more costly alternatives. Because secondary costs are related to the oral and systemic health consequences of wearing RPDs,[14] a significant need exists to advance the materials and technologies associated with these devices.

RPD DESIGN

Providing a useful and comfortable RPD requires careful diagnosis, planning, and maintenance.[3] Previously noted failure rates of RPDs have led many to conclude that RPDs are harmful to periodontal tissue and may contribute to carious lesion formation.[15] However, more recent studies have concluded that while the risk of root caries and gingivitis increases, periodontal diseases generally occur only in patients with poor hygiene and/or a poorly constructed RPD.[3,14] Poor RPD design can exacerbate plaque retention problems, so practitioners should always consider the partial denture design that will best preserve the abutment teeth and edentulous ridges.[16,17]

The steps involved in RPD-related therapy include the evaluation of abutment teeth, abutment tooth position, abutment preparation, adapting the RPD metal framework, relating the edentulous areas to the metal framework, communication with the laboratory, patient education for home care and maintenance, and regular professional recall.[3,10] Because partially dentate patients may have lost their teeth because of poor oral hygiene, home maintenance hygiene, caries intervention strategies, and appropriate use of their removable prosthesis are important for minimizing future complications.[3,18] Accurate custom planning and fabrication of the RPD for each patient is a critical component of success. Variables such as hard/soft tissue anatomy, occlusal relationships, tooth position, and patient desires for esthetics and comfort should dictate the RPD design that can best meet the individual patient's needs.[10]

Traditional RPD design involves the production of stone casts, geometric characterization of the tooth and soft tissues related to the path of insertion, and careful designation of RPD components (major and minor connectors, rests, clasps, and base retention) using a direct waxing method.[3,19] Current digital technologies enable the design of RPD components on 3-dimensional (3D) representations of the patient instead of stone casts by using geometric analysis tools that create designs of micrometer-level accuracy that can be viewed in cross section. The virtual model can then be used to print wax for casting metal frameworks or the direct printing or milling of metal or resin frameworks.

CURRENT RPD MATERIALS

Metal-based frameworks

The earliest dentures were often fabricated with metal.[20] Biocompatible metals such as cobalt-chromium or titanium are the current metals of choice for RPD frameworks.[20,21] The benefits of metal-based frameworks over acrylic resin are that they are used in thin sections and are less bulky, provide high strength and stiffness, conduct heat and cold for a more natural experience, enable designs that minimize the covering of the gingival margins, allow for a stable denture base, undergo repassivation, and are resistant to corrosion.[22,23] The use of titanium to form RPDs has increased and is often recommended for large RPDs.[22] Although titanium has become a proven biocompatible metal, it can cause inflammatory reactions in an estimated 0.6% of patients.[24-28]

Table 1. Advantages and disadvantages of metal and polymer RPDs

Characteristic	Metal RPDs	Polymer (PMMA) RPDs
Esthetics	Less desirable	More desirable
	Nonesthetic clasps and frames[32,33]	Potentially translucent or tooth/gingivally colored[34]
Cost-effectiveness	More expensive	Less expensive[35]
Elastic modulus	More desirable	More desirable
	100-220 GPa[36,37]	3-5 GPa (similar to bone)[21,23,38]
Flexural strength	More desirable	Less desirable
	~2500 MPa[39]	~100 MPa[40]
Ease of repair	Alloy requires soldering, and repairs are difficult and unpredictable[41]	Unknown
Ease of formation	Less desirable	More desirable
	Difficult to form, requiring special equipment[41]	Compatible with existing digital milling and design platforms[34,42]
Ease of handling	Less desirable	More desirable
	Difficult to polish, requires special equipment, difficult to adjust[41]	Easy to polish and adjust[34,42]
Toxicity	More desirable	More desirable
	Sensitization to nickel and possibly cobalt[43]	Generally no cytotoxicity and rare severe reactions/allergicreactions[42,44]
Other	More desirable	More desirable
	Conducts heat/cold, oral galvanism[45]	No metallic taste, good thermal insulator[34]

PMMA, polymethyl methacrylate; RPD, removable partial denture. For toxicity, advantages/disadvantages are patient dependent because of allergies and sensitization reactions.

In addition to potential hypersensitivity, other disadvantages of metal RPDs include esthetic issues with metal display, oral galvanism, adverse tissue reactions, osteolysis of abutment teeth, and biofilm production.[21,23,24] A surface layer of protein typically forms on the metal prosthesis and is a critical component of the biocompatibility of titanium.[23] This initial protein layer may, however, enable colonization of microorganism in the area, allowing the development of a biofilm. Antimicrobials are not effective in destroying biofilm, and so infections can only be treated with physical removal or disinfection of the prosthesis. Removable prostheses also act as a reservoir for respiratory pathogens.[29]

Although cobalt-chromium is widely considered the best material for a denture framework, the physical properties of the material itself are not ideal. Keltjens et al[30] investigated the fit of retainers after 8 years of normal use and found that the majority of metal clasps were distorted and that over time they did not fit the abutment correctly. Another group later investigated the physical properties of cobalt-chromium clasps and applied a validated nonlinear finite elemental model that revealed the patterns of stress and strain distributions of different metals during RPD use.[31] Through this method, they were able to characterize how cobalt-chromium distorts under the stress produced during RPD use and outline the physical limitations of the material for use in retentive clasps.[31]

Polymer-based frameworks

Because of the drawbacks of metal-based frameworks, the use of metal-free materials, including high-performance polymers such as polyethylene glycol, polymethyl methacrylate, and aryl-ketone polymers, has been investigated.[23] Some advantages of polymer-based frameworks over those made of metal are that they improve esthetics because of their translucency and color, are more cost-effective, have higher elasticity, are straightforward to produce, are lightweight, have low water sorption and solubility, and are easily repaired and reproduced (Table 1).[21,23,32-46]

The disadvantages of polymer frameworks include low thermal conductivity, brittleness, less mechanical strength than metal (more problematic for mastication), a high coefficient of thermal expansion, a relatively low modulus of elasticity, faster deterioration than metal, and possible cytotoxicity because of the leaching of chemicals.[35,44,47] In addition, polymer-based frameworks have not typically included key RPD design features such as rests and indirect and direct retention components. This has presented many problems for their broader use. However, a promising polymer-based framework has recently been introduced that consists of a modified polyetheretherketone polymer (BioHPP) frame combined with acrylic resin denture teeth and a conventional acrylic resin denture base.[48] While the BioHPP frame includes critical RPD design features previously lacking in polymer-based prosthetics, the absence of clinical studies along with concerns about how the material may behave under fatigue stress during use suggests that it should be used with caution and cannot yet be recommended as an alternative to cobalt-chromium.[48]

Current metal- and polymer-based RPDs can be problematic for patients, and given that the demand for RPDs is increasing, there is a need to develop improved materials for their fabrication (Table 2).[35] Given the rapid transition to digitally designed and fabricated prostheses, the need for new materials that can be developed using these techniques is even more important.

Table 2. Ideal requirements for denture base materials[35]

Property	Requirement
Biological	Should be nontoxic, nonirritant, and noncarcinogenic.
Chemical	Should be insoluble in oral fluids or any other fluids being taken by patient.
	Should not absorb oral fluids or any other fluids being taken by patient as it causes dimensional changes.
	Should adhere well to artificial teeth and liners.
Mechanical	Modulus of elasticity should be high. Enables denture base to be rigid against masticatory forces.
	Resilience should be high to protect underlying soft tissues by absorbing masticatory forces.
	Should have high elastic limit and proportional limit to prevent permanent deformation when stressed.
	Should have adequate mechanical strength to resist fracture under repeated masticatory forces.
	Should be dimensionally stable.
	Should have adequate abrasion resistance.
	Specific gravity should be low (especially for maxillary dentures).
Thermal	Should be good thermal conductor.
	Coefficient of thermal expansion should match that of artificial teeth.
	Softening temperature should be more than boiling temperature of water.
Esthetic	Should exhibit sufficient translucency so that it can be made to match appearance of tissues.
	Should be capable of being tinted or pigmented.
Other	Should maintain desirable properties for extended periods after manufacture.
	Should be inexpensive.
	Should be easy to manipulate.
	Should be radiopaque so can be detected if some part of denture is accidentally swallowed.
	Should be easy to repair.
	Should be easy to clean.
	Should have longer shelf life.

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ORAL HEALTH EVALUATION

Follow-up and future studies

The health of the periodontium and remaining teeth, particularly abutment teeth, may be at higher risk with the use of RPDs. Both patient follow-up and future clinical trials should evaluate these areas.[49] RPDs are often held in place with clasps on abutment teeth that provide an area for plaque accumulation, which can be difficult for patients to clean if they do not regularly remove the prosthesis.[49] Gingival plaque accumulation can quickly result in caries, root caries, and periodontitis, especially with acrylic resin materials. Because irregularities in the denture can provide microhabitats for plaque biofilms, the provision of a prosthesis can result in bacteria that may be pathogenic and difficult to treat. Because of mucosal inflammation, dentures can also cause trauma such as stripping of gingival tissue and pain or ulceration; this can be addressed by using correct RPD design (Fig. 1).[50] During recall appointments, particular attention should be paid to abutment tooth health, proper RPD adaptation, tissue support, occlusal function, hygiene, and caries intervention strategies.

Measurement of patient satisfaction and compliance

Patient satisfaction with the prosthesis can have a profound impact on the success of treatment because dissatisfaction with an RPD will likely lead to underuse and subsequent rehabilitation failure. A retrospective study on factors that affect the continued use and patient satisfaction of RPDs found that 39% of RPDs were no longer used within 5 years and that patient age, location of the edentulous area, number of occluding teeth and rests, and pain all significantly affected patient satisfaction and consequently compliance.[51] Additionally, the esthetic appearance of RPDs is particularly valued by patients and should be addressed to prevent lack of RPD use.[47]

Because dentists tend to focus on the physical function of the teeth while patients are more concerned with the social implications of RPDs, understanding why patients stop wearing their RPDs is critical.[51] Studies with long-term follow-up on patient satisfaction and compliance and multivariate analyses to control for the influence of multiple possible confounding variables are needed to further understand the impact of RPD therapy.

FUTURE DIRECTIONS AND NEEDS

Digital design

RPD-associated problems such as poor patient satisfaction and compromised function, esthetics, and oral health need to be addressed.[9] Improvements in the design, fabrication, fit, and esthetics of RPDs are essential and could be facilitated by the development of new materials with adequate strength and flexibility for occlusal rests, indirect retention, and retentive clasp assemblies. RPD frameworks made of novel materials with increased durability, improved strength, the desired

Figure 1. Removable partial denture–induced oral injuries. A, Influence of resin clasp without metal rest on gingival tissue. B, Compression and inflammation of marginal gingiva of abutment tooth due to depression of denture base. C, Nonmetal clasp denture that overloads abutment teeth (intraoral view with denture). D, Terminal abutment tooth (mandibular right first premolar) presenting severe mobility. (Reprinted with permission from Elsevier from Fueki K, Ohkubo C, Yatabe M, Arakawa I, Arita M, Ino S, et al. Clinical application of removable partial dentures using thermoplastic resin. Part II: Material properties and clinical features of non-metal clasp dentures. J Prosthodont Res 2014;58:71-84. Creative Commons License: https://creativecommons.org/licenses/by-nc-nd/4.0/.)

balance between flexibility and rigidity, while improving the framework esthetics, would be broadly beneficial.

Digital technology and its application to the design and fabrication of a single tooth to a complete-arch prosthesis is advancing rapidly. Computer-aided design and computer-aided manufacturing (CAD-CAM) systems are being widely used in the design and fabrication of fixed, implant, and removable prostheses. CAD-CAM techniques have been investigated as a method of surveying 3D-scanned dental casts to create RPD frameworks.[10] Dental laboratory technicians and clinicians are using software to design RPD frameworks from digital impressions obtained from both intraoral and laboratory-based digital scanning strategies. The primary obstacle preventing the broad application of a complete RPD digital workflow has been the difficulty and expense associated with producing the metal frameworks.

Digital dentistry using CAD-CAM technology, high-precision 3D printers and scanners, and industrial casting and production techniques can be expected to improve the fit, esthetics, and functional components of RPDs while reducing costs and labor, thus increasing efficiency and manufacturing outcomes. However, selective laser melting, milling, and other digital fabrication methods for metal frameworks are currently restrictive.[52] Technology such as 3D scanners and denture design software modules promise advancements in RPD production with digitally designed RPDs that can be printed in wax and cast/fabricated conventionally.[10] Open-architecture scanners combined with design software can allow for a precise, digitally designed, machine-produced removable prosthesis that is tailor-made to each individual patient's needs.

Digital solutions allow the application of advanced materials that would otherwise not be used for RPD fabrication. Polymers would be of special interest because of their ease of milling/fabrication and desirable properties. The ability to design and produce the RPD digitally

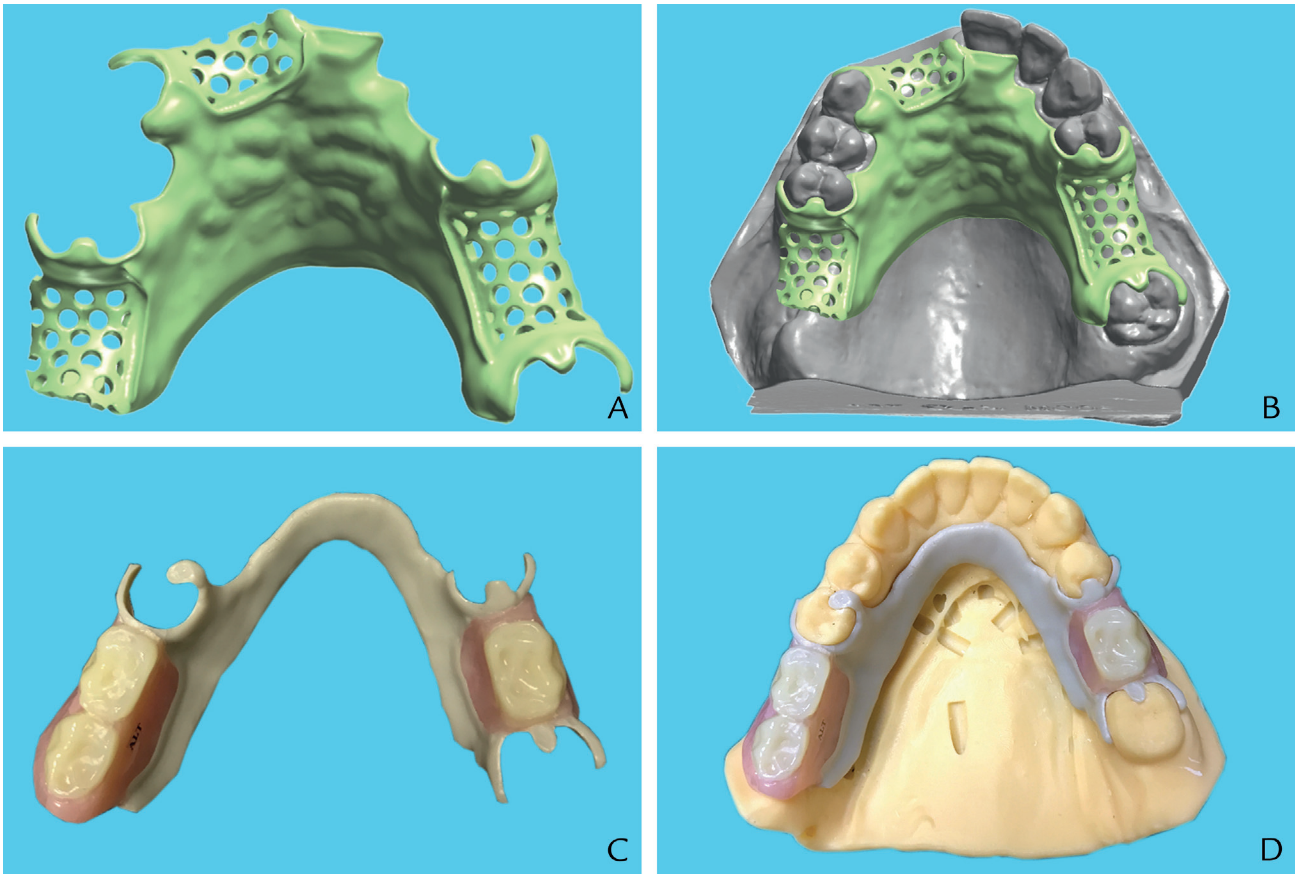

Figure 2. A, Computer-generated image of digitally designed RPD framework, possible with Asahi Kasei Plastics (AKP) resin. B, Computer technology combined with new polymers provide more precise fitting of denture framework. C, Mandibular RPD using AKP resin as framework (digitally fabricated). D, Overall fit of RPD on physical model. RPD, removable partial denture.

opens up the entire range of biomedical polymers for the custom patient application that dentistry dictates (Fig. 2). The potential for design control, manufacturing flexibility, and repeatable precision, coupled with the application of advanced materials, promises significant advances in RPD-based therapies.

Improvements in materials for RPDs

The advent of new polymers with increased biocompatibility, durability, and elasticity and that are more esthetically pleasing and cost-effective offers significant advances for RPD-based prosthetics. Various investigations have focused on the development of new polymers by modifying existing materials with the addition of fillers such as glass, silica, borosilica, and fused quartz.[44] Additionally, a range of alternative binders and processing techniques are being examined to develop a dental polymer better suited to clinical application. Polymers are well suited to fabrication in the new digital workflow, and establishing polymer-based materials and fabrication strategies that will allow for the incorporation of key design features such as rests and indirect and direct retention components will significantly expand their applications.

The mechanical and physical properties of recently developed polymers, such as the aryl-ketone polymers, are similar to those of bone and dentin.[38] This can allow for the production of RPDs that are less intrusive while remaining stable and comfortable. In addition, many of these polymers are heat resistant and can offer autoclave disinfection of the prostheses. However, more research is required in the application of currently available polymers for RPDs and there is a need for development of new materials that meet the key design requirements for RPDs. As the demand for RPDs increases, the prospects for developing polymers with improved structure and biocompatibility for dental applications are promising.

An ideal RPD framework polymer should possess adequate mechanical properties for functions such as reciprocation and resistance to impact forces and excessive wear. A polymer-based RPD frame should incorporate key design features such as occlusal rests and direct retention arms/strategies. In addition, it would esthetically match the teeth and mucosal tissues of the mouth and provide long-term stability.[44] Appropriate polymers should also be chemically stable (no deterioration or leaching of monomers), biocompatible, and stable at various temperatures, and it should have rheometric properties that allow for elastic deformation and recovery with the application and removal of stress (resistance to permanent deformation).[44] Advances in mechanical and esthetic properties of new RPD materials may provide the opportunity to reconsider fundamental partial denture design principles that, for the past 80 years, have been largely based on the properties of cobalt-chromium. These novel materials offer potential design innovations, including improvements in the distribution of mechanical stress associated with RPD function. Advancements in RPD materials such as these have the potential to significantly improve patient outcomes such as satisfaction with function and esthetics.

Research

More research is needed regarding the effects of RPDs on the oral health of soft tissue and remaining teeth comparing commonly used materials with emerging materials for the fabrication of RPDs. Randomized clinical trials (RCTs) are considered the highest-quality design for informing health care interventions and for performing metaanalyses to answer important clinical questions; however, a recent review found that between 1986 and 2014, only 86 articles reported on RCTs for removable prosthodontics, and of those, only 26% reported on non-implant-assisted removable prosthodontics such as RPDs.[53] Furthermore, a Cochrane systematic review on interventions for the partially absent dentition identified only 5 trials evaluating RPDs for inclusion.[1] Three of the trials evaluated different aspects of RPD design,[54-56] one trial evaluated different materials used in RPDs,[57] and another compared different fabrication techniques.[58] It can be concluded that there is a shortage of clinical trial data on RPDs, leading to a lack of evidence. There is no agreed minimum outcome data set to assess the prosthesis and no consensus over which outcome measures, including patient-reported outcomes, should be collected.

Investigation into the outcomes of interest in previous clinical trials may be helpful in determining gaps in the field, areas of improvement, and future study design. Over the last 3 decades, among the RCTs in removable dental prosthetics, the most frequent primary outcomes were based on biology, physiology, and patient satisfaction.[53] Disease-oriented measures of mastication have also been reported as both primary and secondary outcomes. Prosthesis survival, rehabilitation success rate, variables associated with denture quality, and maintenance and mechanical complications were other commonly reported items. Ideally, future research should include key areas of consideration such as longevity and survival of the RPD, critical RPD design features and materials, functionality of the prosthesis and how it affects the patient, the psychosocial impact of wearing RPDs, including patient satisfaction and quality of life, and the economic impact of treatment with RPDs over both the short and long term. Because numerous outcomes associated with clinical, dental, and patient factors influence the best treatment options for partial edentulism, more RCTs that evaluate all of the consequential concerns are necessary to inform and ultimately advance the field.

CONCLUSIONS

In the coming years, the number of patients with partial edentulism will rise along with the need for cost-effective treatments such as RPDs. Complications and treatment failures may occur with RPDs, and rigorous research is needed to examine the strengths and weaknesses of different RPD designs and new techniques and materials. Proper evaluation of the dentition state, tooth position, abutment preparation, adapting structures within the RPD, patient education, timely recall, and maintenance are only a few of the steps required for success. Treatment with RPDs should ideally result in improvements in overall oral health, patient satisfaction, and compliance.

Research and advancements in the application of digital technologies and improved materials such as biocompatible metals and polymers have the potential to resolve many of the issues surrounding RPD use and oral health. Digital strategies widen the scope of therapeutic applications for partial dentures as a result of improved design and production control, new materials, and improved efficiencies that will likely enhance outcomes and improve patient experiences. The need for RPDs is expected to increase. RPD strategies must continue to evolve and improve to best care for the growing partially edentulous population. The combination of improved materials, digital design, research, and education as it relates to caring for patients with partial edentulism promises to improve the quality of life for our patients.

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Acknowledgments
The authors thank Bianca Shemper, Solvay Dental 360, for providing data and for critical review and insights, and Debika Chatterjea, MedVal Scientific Information Services LLC, for providing medical writing and editorial assistance.