Sains Malaysiana 52(6)(2023): 1759-1770
http://doi.org/10.17576/jsm-2023-5206-12

Methods of Evaluating Adaptation and Accuracy of Additive Manufactured Removable Partial Dentures: A Scoping Review

(Kaedah Menilai Penyesuaian dan Ketepatan Penghasilan Aditif Gigi Palsu Sebahagian Boleh Tanggal: Suatu Kajian Mengskop)

SAFA ELHADERY[1], NORLELA YACOB[2], SYARIDA HASNUR SAFII[1], NORLIZA IBRAHIM[3], ZUBAIDAH ZANUL ABIDIN[1] & NOSIZANA MOHD SALLEH[1*]

[1]Department of Restorative Dentistry, Faculty of Dentistry, Universiti Malaya, 50603, Kuala Lumpur, Malaysia
[2]Department of Conservative Dentistry & Prosthodontics, Faculty of Dentistry, Universiti Sains Islam Malaysia (USIM), 71800, Nilai, Negeri Sembilan, Malaysia
[3]Department of Oral and Maxillofacial Clinical Sciences, Faculty of Dentistry, Universiti Malaya, 50603 Kuala Lumpur, Federal Territory, Malaysia

Received: 11 January 2023/Accepted: 13 June 2023

ABSTRACT

This study aimed to provide a comprehensive review of various recent methods that can be used to assess the fit and accuracy of additive-manufactured removable partial dentures (RPDs), focusing on 3D-printed RPDs. An electronic search of the English language literature from January 2000 to February 2022 was performed using four databases: Medline/PubMed, Scopus, Web of Science, and EBSCOhost, using relevant keywords. The parameters of interest were extracted and tabulated. Of 936 retrieved studies, 26 studies were included. Most of the studies were laboratory studies, conducted between 2011 and 2022, did not include control group, used stone cast model as reference, used direct 3D printing method, and polished the final RPD framework. Methods of assessment can be divided into two categories: 1) qualitative assessment which is based mainly on visual inspection or tactile sense, and 2) quantitative assessment which includes optical assessment (with or without a registration material) and computerized assessment based on surface-matching software programs. In conclusion, computerized assessment using different surface matching software provides more accurate and precise quantitative assessment of denture fit and allows researcher and practitioner to detect minute dimensional changes that cannot be detected visually.

Keywords: Accuracy; digital dentistry; fit; removable partial dentures; trueness; 3D-printing

ABSTRAK

Penyelidikan ini bertujuan membuat tinjauan menyeluruh tentang kaedah yang digunakan untuk menilai padanan dan ketepatan gigi palsu sebahagian (RPD) memfokuskan kepada dentur yang dihasilkan secara cetakan 3D. Pencarian kepustakaan elektronik berbahasa Inggeris dari Januari 2000 hingga Februari 2022 dilakukan menggunakan empat pangkalan data: Medline/PubMed, Scopus, Web of Science dan EBSCOhost menggunakan kata kunci yang berkaitan. Beberapa parameter telah dinilai dan dijadualkan. Daripada 936 kajian yang dijumpai, hanya 26 kajian dipilih. Sebahagian besar adalah kajian makmal yang dijalankan di antara tahun 2011 dan 2022, tidak melibatkan kumpulan kawalan, menggunakan model tuangan sebagai rujukan, menggunakan kaedah cetakan 3D secara langsung dan menggilap kerangka RPD akhir. Kaedah penilaian dibahagi kepada dua kategori: 1) penilaian kualitatif yang menggunakan pemeriksaan secara visual atau sentuhan dan 2) penilaian kuantitatif termasuk secara optikal (menggunakan bahan registrasi atau tanpanya) dan penilaian secara berkomputer menggunakan program perisian padanan-permukaan. Kesimpulannya, penilaian secara berkomputer menggunakan program perisian padanan-permukaan memberi keputusan penilaian kuantitatif yang lebih tepat dan terperinci kepada padanan gigi palsu dan membolehkan pengkaji dan pengamal pergigian mengesan perubahan dimensi walaupun kecil yang tidak boleh dikesan oleh mata kasar.

Kata kunci: Cetakan 3D; gigi palsu sebahagian; ketepatan; padanan; pergigian digital

INTRODUCTION

A well-constructed removable partial denture (RPD) is determined by the accuracy of its fit in the mouth. Accurately fit RPD is one of the essential parameters for the restoration to succeed (Academy of Prosthodontics 1995; Al Mortadi, Alzoubi & Williams 2020). The fit of RPD components such as rest, clasps, and connectors is crucial in enhancing the function of the denture e.g., the fit of a connector helps protect the stability of the periodontal structures and oral mucosa (Frank et al. 2000). Ill-fitting conventionally fabricated cobalt-chromium RPD has been identified as one of the most common complaints amongst RPD wearers (Almufleh et al. 2018; Fenlon et al. 1993). An ill-fitting denture can cause oral health problems such as caries (especially root caries), periodontitis, oral candidiasis, and denture stomatitis (Preshaw et al. 2011). Dimensional changes have been identified as one of the main causes of ill-fitting RPD. The dimensional distortions can occur during conventional casting process because of wax pattern distortion, contraction of chrome cobalt alloy, or technical manual errors (Campbell et al. 2017; Fenlon et al. 1993).

In the era of digital dentistry, the fabrication of RPDs has undergone an evolution from conventional casting to digital fabrication. Theoretically, the combination of computer-aided design (CAD) technology with 3D-printing should be more accurate than conventional framework fabrication because fewer steps are required for RPD construction which lead to reduction of errors during fabrication (Arnold et al. 2018; Bibb et al. 2006; Williams et al. 2006). Earlier studies assessing fit of RPDs fabricated by computer-aided design/computer-aided manufacturing or CAD/CAM (milling) and rapid prototyping (3D printing) showed a comparable result to conventional fabricated RPDs (Batalha & Araújo 2017; Carneiro Pereira et al. 2019; Mendes et al. 2019). 3D printing allows fast production of dentures with less wastage of materials compared to milling (Alharbi, Wismeijer & Osman 2017; Azari & Nikzad 2009). The advancement in 3D-printing technology facilitates the use of metal, resin, and other novel materials for denture production (Torabi, Farjood & Hamedani 2015). Since methods of RPD fabrication have advanced toward digitization, so does fit assessment of RPD frameworks.

Visual and tactile assessment using a mouth mirror and a dental explorer were the most popular approach to evaluate the acceptability of framework fit in a clinical setting (British Society for the Study of Prosthetic Dentistry 1981). For extra-oral assessment, a proper seating of the framework on the cast is considered a successful fit (Lang & Tulunoglu 2014). However, these assessments are qualitative in nature and provide a restricted evaluation of the fit. Concern about the gap distance between a framework and the corresponding tissues that is clinically acceptable has increased among researchers. Usually, the gap is assessed using a registration material such as silicone. The thickness of the registration material represents the gap distance often measured by a digital calliper or a microscope (Dunham et al. 2006; Ye et al. 2017). As a basis for evaluation of misfits, a gap of 0 to 50 μm is considered intimate contact, 50-310 μm is clinically acceptable, and more than 310 μm is considered a misfit (Negm, Aboutaleb & Alam-Eldein 2019; Soltanzadeh et al. 2019). Using these measurements, a study found that 76% of the conventional fabricated RPDs have no optimal contact with the rest seats (Dunham et al. 2006). This method of chair-side fit assessment is also acceptable for the conventionally fabricated RPDs (Baig, Tan & Nicholls 2010). Nevertheless, this assessment does not provide three-dimensional evaluation and is not consistent.

In 3D-printing technology, the trueness refers to the closest results of the 3D-printed models to the reference model, which indicates quantitative similarity between the 3D-printed data and the reference design data (International Organization for Standardization 1998). Trueness is an essential parameter used to investigate the accuracy of a 3D-printed RPD. It indicates the amount of deviation of a 3D-printed prosthesis from the originally designed data, which cannot be assessed by optical and visual assessments (Negm, Aboutaleb & Alam-Eldein 2019; Peng et al. 2020).

In the last few years, several studies have tested various methods used to evaluate fit of the 3D-printed (3DP) RPD framework (Arnold et al. 2018; Bajunaid et al. 2019; Batalha & Araújo 2017; Bibb et al. 2006; Cabrita et al. 2021; Carneiro Pereira et al. 2019; Chen & Guang 2012; Chen et al. 2011; Chen et al. 2019; Eggbeer, Bibb & Williams 2005; Gan et al. 2018; Hu, Pei & Wen 2019; Kattadiyil et al. 2014; Lee et al. 2017; Negm, Aboutaleb & Alam-Eldein 2019; Peng et al. 2020; Soltanzadeh et al. 2019; Takahashi et al. 2020; Tasaka et al. 2020, 2019; Torii et al. 2018; Tregerman et al. 2019; Williams et al. 2006; Wu, Li & Zhang 2017; Xie et al. 2020; Ye et al. 2017). Few reviews have been published recently on the fit accuracy of the 3DP RPDs (Ahmed et al. 2021; Al Mortadi, Alzoubi & Williams 2020; Mai et al. 2022).

However, there is a lack of review on the available methods used to assess the adaptation and accuracy of the 3D-printed frameworks. This scoping review, therefore, aimed at summarizing the current methods being used to assess the fit accuracy of the 3DP RPDs. The main objective of this systematic review was to identify the recent evidence on current techniques being used to assess the fit and accuracy of the 3D printed RPDs. The secondary objective was to assess and evaluate the accuracy and fit of 3DP RPDs in comparison to other conventional methods of RPD fabrication.

METHODS

The present review was conducted in compliance with The Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMS-ScR) Statement (Tricco et al. 2018) to answer the following question: What are the available methods being used to assess the fit accuracy of the 3D-printed removable partial dentures?

SEARCH STRATEGY AND ELIGIBILITY CRITERIA

Four electronic databases i.e., Medline/PubMed, Scopus, Web of Science, and EBSCOhost, were used to search for articles published between 2000 and February 2022. The following relevant keywords were used in data extraction: 'Fit' OR 'fitting surface accuracy' OR 'internal discrepancy' OR 'surface adaptation' OR 'denture trueness' OR 'denture precision' OR 'denture accuracy' AND '3D printing' OR 'three-dimensional printing' OR 'additive manufacturing' OR 'selective laser melting' OR 'SLM' OR 'Selective laser sintering' OR 'SLS' OR 'Rapid Prototyping' OR 'rapid manufacturing' OR 'computer aided design' OR 'CAD' AND 'removable partial denture' OR 'removable prostheses' OR denture framework OR 'denture' OR 'partial' OR 'removable' OR 'PEEK denture' OR 'PMMA denture base' OR 'denture polymers' OR 'denture base'.

EndNote software program was used to remove duplication of the records. The titles and abstracts of the remaining records were analysed independently by two reviewers (S.S. & N.Y.). The inter-rater reliability was tested using the kappa statistic and any disagreements were resolved by consulting a third reviewer (N.S). The full texts of the potentially eligible articles were downloaded for further screening. The articles were screened according to the following inclusion criteria: *in-vitro* (experimental) studies or *in-vivo* clinical trials reporting assessment of accuracy, trueness, adaptation, and internal discrepancy of 3D-printed removable partial frameworks, published in English language, full-length original research, and published in the last twenty years. Studies on milling fabricated RPD, editorials, and review articles were excluded.

DATA EXTRACTION AND OUTCOMES

Two authors (S.S. & N.Y.) extracted the parameters of interest from each study as follows: author(s) and year of study, study design, Kennedy's classification of the partially edentulous model/jaw, control group, source of reference used for RPD framework design/printing, type of the 3DP, polishing of the final RPD, and main outcomes. Furthermore, the type of assessment (qualitative or quantitative), method of assessment, type of measurement, area of measurement, and materials used were also extracted. The main outcome of each study was also presented to provide information on the fit and accuracy of 3D printed RPDs in comparison to other types of RPDs.

RESULTS

SEARCH RESULTS AND SELECTION OF THE ELIGIBLE STUDIES

The complete search strategy according to the PRISMA guidelines is presented in Figure 1. A total of 936 studies were retrieved in the initial search of the databases. Of these, 729 records were excluded as duplicates yielding 207 records that were screened based on titles and abstracts. Of these, 173 studies were excluded as irrelevant. Then, the full text of the remaining 34 studies was extracted and screened for eligibility, which led to the exclusion of nine studies for different reasons (e.g., non-English language and the RPD was fabricated by milling method). A manual search of the bibliography lists of the included studies added one study. Finally, 26 studies (Arnold et al. 2018; Bajunaid et al. 2019; Batalha & Araújo 2017; Bibb et al. 2006; Cabrita et al. 2021; Carneiro Pereira et al. 2019; Chen & Guang 2012; Chen et al. 2019; Chen et al. 2011; Eggbeer, Bibb & Williams 2005; Gan et al. 2018; Hu, Pei & Wen 2019; Kattadiyil et al. 2014; Lee et al. 2017; Negm, Aboutaleb & Alam-Eldein 2019; Peng et al. 2020; Soltanzadeh et al. 2019; Takahashi et al. 2020; Tasaka et al. 2020, 2019; Torii et al. 2018; Tregerman et al. 2019; Williams et al. 2006; Wu, Li & Zhang 2017; Xie et al. 2020; Ye et al. 2017) met the inclusion criteria and were processed for qualitative analysis.

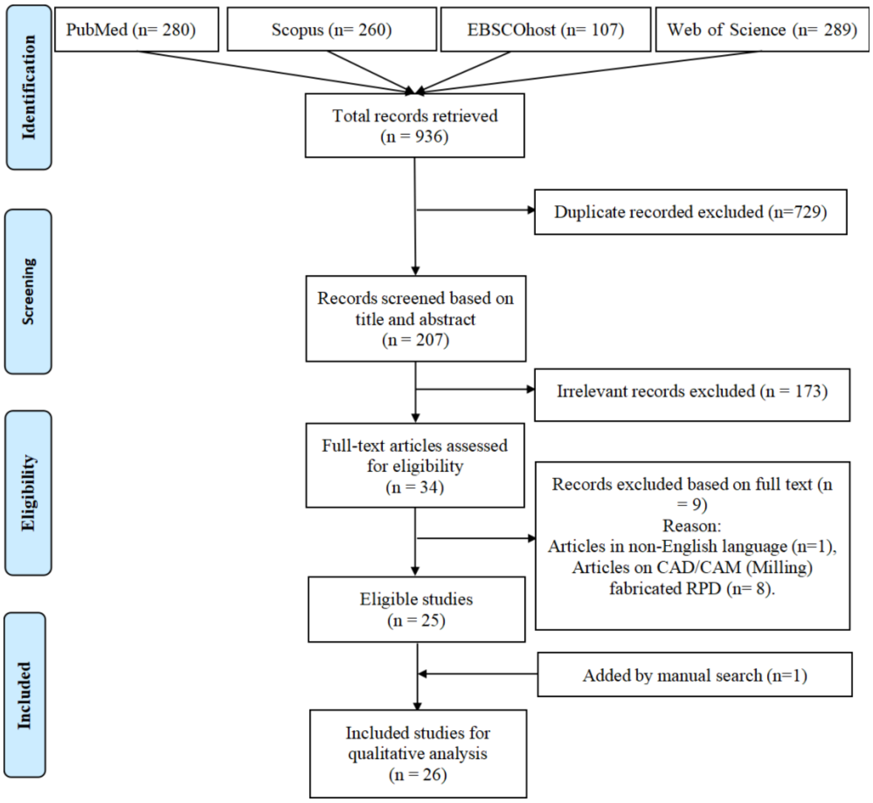

FIGURE 1. The flow diagram of the search process

CHARACTERISTICS OF THE INCLUDED STUDIES

The main characteristics of the included studies are presented in Table 1. Most of the included studies were conducted between 2011 and 2022 (Arnold et al. 2018; Bajunaid et al. 2019; Batalha & Araújo 2017; Cabrita et al. 2021; Carneiro Pereira et al. 2019; Chen & Guang 2012; Chen et al. 2019; Chen et al. 2011; Gan et al. 2018; Hu, Pei & Wen 2019; Kattadiyil et al. 2014; Lee et al. 2017; Negm, Aboutaleb & Alam-Eldein 2019; Peng et al. 2020; Soltanzadeh et al. 2019; Takahashi et al. 2020; Tasaka et al. 2020, 2019; Torii et al. 2018; Tregerman et al. 2019; Wu et al. 2017; Xie et al. 2020; Ye et al. 2017), with only three done in 2005 and 2006 (Bibb et al. 2006; Eggbeer, Bibb & Williams 2005; Williams et al. 2006). Fifteen studies were experimental (laboratory) in design (Arnold et al. 2018; Bajunaid et al. 2019; Bibb et al. 2006; Chen & Guang 2012; Chen et al. 2011; Chen et al. 2019; Eggbeer, Bibb & Williams 2005; Negm, Aboutaleb & Alam-Eldein 2019; Peng et al. 2020; Soltanzadeh et al. 2019; Takahashi et al. 2020; Tasaka et al. 2020, 2019; Torii et al. 2018; Xie et al. 2020), while two studies were randomized controlled trials (RCT) (Gan et al. 2018; Ye et al. 2017), two were clinical trials (CT) (Lee et al. 2017; Tregerman et al. 2019), and seven studies were case reports (CR) (Batalha & Araújo 2017; Cabrita et al. 2021; Carneiro Pereira et al. 2019; Hu, Pei & Wen 2019; Kattadiyil et al. 2014; Williams et al. 2006; Wu et al. 2017).

Twenty-two studies (Arnold et al. 2018; Bajunaid et al. 2019; Batalha & Araújo, 2017; Bibb et al. 2006; Cabrita et al. 2021; Carneiro Pereira et al. 2019; Chen & Guang 2012; Chen et al. 2011; Chen et al. 2019; Eggbeer, Bibb & Williams 2005; Hu, Pei & Wen 2019; Kattadiyil et al. 2014; Lee et al. 2017; Negm, Aboutaleb & Alam-Eldein 2019; Peng et al. 2020; Soltanzadeh et al. 2019; Tasaka et al. 2020, 2019; Tregerman et al. 2019; Williams et al. 2006; Wu et al. 2017; Ye et al. 2017) used different Kennedy's classifications of the edentulous jaw/model for both maxilla and mandible, with more dominance of class II and III with or without modifications. However, three studies (Takahashi et al. 2020; Torii et al. 2018; Xie et al. 2020) used tooth die simulation models of the first molar, and one study (Gan et al. 2018) used a dentate model.

Nine studies (Arnold et al. 2018; Bajunaid et al. 2019; Chen et al. 2019; Peng et al. 2020; Soltanzadeh et al. 2019; Torii et al. 2018; Tregerman et al. 2019; Xie et al. 2020; Ye et al. 2017) included conventional RPD using the lost wax technique (LWT) as a control group, while the remaining 17 studies assessed the 3DP RPD without control group. The type of the reference model varied greatly among the studies; eight studies (Arnold et al. 2018; Batalha & Araújo, 2017; Bibb et al. 2006; Cabrita et al. 2021; Eggbeer, Bibb & Williams 2005; Lee et al. 2017; Negm, Aboutaleb & Alam-Eldein 2019; Ye et al. 2017) used stone cast model, seven studies (Carneiro Pereira et al. 2019; Gan et al. 2018; Hu, Pei & Wen 2019; Kattadiyil et al. 2014; Tregerman et al. 2019; Williams et al. 2006; Wu et al. 2017) used an intra-oral scanner (IOS) directly for the patient's mouth, two studies (Chen et al. 2019; Soltanzadeh et al. 2019) used resin cast model, one study (Bajunaid et al. 2019) used metal cast model, one study (Tasaka et al. 2020) used plaster cast model, two study (Peng et al. 2020; Tasaka et al. 2019) reported cast model without any specifications of the type, and two studies (Chen & Guang 2012; Chen et al. 2011) did not report the type of the reference.

Regarding the types of printing, 17 studies used direct printing of the RPD framework, five studies (Batalha & Araújo 2017; Carneiro Pereira et al. 2019; Eggbeer, Bibb & Williams 2005; Kattadiyil et al. 2014; Lee et al. 2017) used indirect printing, which included direct printing of the framework pattern (resin) and then casting the pattern in the conventional method, and four studies (Arnold et al. 2018; Negm, Aboutaleb & Alam-Eldein 2019; Takahashi et al. 2020; Tasaka et al. 2019) used both direct and indirect printing methods. Of the included studies, 17 reported polishing of the final framework, while seven studies (Batalha & Araújo 2017; Chen & Guang 2012; Chen et al. 2011; Chen et al. 2019; Peng et al. 2020; Takahashi et al. 2020; Tasaka et al. 2020) did not clearly state this procedure, and two studies (Tasaka et al. 2019; Torii et al. 2018) stated that the final framework was not polished.

As a secondary outcome of this review, the fit and accuracy of the 3DP RPDs was represented as an important finding of each included study (Table 1) whereby 16 studies (without a control group) reported that the fit of the RPD framework was clinically acceptable, and another study (Negm, Aboutaleb & Alam-Eldein 2019) without a control group reported that the fit was not accepted. However, four studies (Bajunaid et al. 2019; Peng et al. 2020; Tregerman et al. 2019; Xie et al. 2020) reported that the 3DP RPD was better in fit than the control group (LWT). In comparison, two studies (Arnold et al. 2018; Ye et al. 2017) reported less fit and accuracy of the 3DP RPD compared to the LWT group, two studies (Chen et al. 2019; Soltanzadeh et al. 2019) reported less fit of the 3DP RPD compared to the LWT group, but clinically acceptable. One study (Torii et al. 2018) reported no significant differences between the fit of LWT group and the 3DP group.

METHODS OF FIT ASSESSMENTS

In general, methods of fit accuracy can be divided into two main categories (Figure 2): The first category is the qualitative assessment, in which the fit and accuracy of the framework was assessed using visual inspection or tactile sense without any numerical measurement (Bibb et al. 2006; Cabrita et al. 2021; Eggbeer, Bibb & Williams 2005; Hu, Pei & Wen 2017; Kattadiyil et al. 2014; Carneiro Pereira et al. 2019; Tregemen et al. 2019; William et al. 2006; Wu et al. 2020). The second category is the quantitative assessment, in which the fit and accuracy of the framework was assessed numerically using either optical instruments with or without assistant materials (Arnold et al. 2018; Bajunaid et al. 2019; Gan et al. 2018; Lee et al. 2017; Takahashi et al. 2020; Torii et al. 2018; Xie et al. 2020) or by using computer software programs (Chen & Guan 2012; Chen et al. 2011; Chen et al. 2019; Negm, Aboutaleb & Alam-Eldein 2019; Peng et al. 2022; Soltanzadeh et al. 2018; Tasaka et al. 2020, 2019). Some studies performed more than one type of assessment (Batalha et al. 2017; Ye et al. 2017). Further details about the assessment methods are shown in Table 2.

VISUAL ASSESSMENT METHOD

Nine studies (Bibb et al. 2006; Cabrita et al. 2021; Carneiro Pereira et al. 2019; Eggbeer, Bibb & Williams 2005; Hu, Pei & Wen 2019; Kattadiyil et al. 2014; Tregerman et al. 2019; Williams et al. 2006; Wu et al. 2017) assessed the overall adaptation of the framework qualitatively by direct visual inspection (naked eye) or tactile sense. Of these, one study (Tregerman et al. 2019) also used a close-ended questionnaire answered by five clinicians to judge the fit accuracy visually. Another two studies (Batalha & Araújo 2017; Ye et al. 2017) used both qualitative and quantitative methods to evaluate the RPD.

TABLE 1. Main characteristics of the included studies

Study	Study design	RPD class	Control group	Source of reference	Type of 3DP	Polishing	Important findings
Eggbeer, Bibb & Williams (2005)	Laboratory	Man: Class III mod 1	No	Stone cast model	Indirect	Yes	3DP has acceptable fit
Bibb et al. (2006)	Laboratory	Man: Class I	No	Stone cast model	Direct	Yes	3DP has acceptable fit
Williams et al. (2006)	CR	Man: Class I	No	Patient's mouth (IOS)	Direct	Yes	3DP has acceptable fit
Chen et al. (2011)	Laboratory	Max: Class II	No	NR	Direct	NR	3DP has acceptable fit
Chen & Guan (2012)	Laboratory	Class III	No	NR	Direct	NR	3DP has acceptable fit
Kattadiyil et al. (2014)	CR	Max: Class III	No	Patient's mouth (IOS)	Indirect	Yes	3DP has acceptable fit
Batalha & Araújo (2017)	CR	Man: Class I mod 1	No	Stone cast model	Indirect	NR	3DP has acceptable fit
Hu, Pei & Wen (2017)	CR	Max: Class I	No	Patient's mouth (IOS)	Direct	Yes	3DP has acceptable fit
Lee et al. (2017)	CT	Class I, II, III	No	Stone cast model	Indirect	Yes	3DP has acceptable fit
Ye et al. (2017)	RCT	Max: Class I mod 1; Man: Class II mod 1	LWT	Stone cast model	Direct	Yes	3DP has less fit
Arnold et al. (2018)	Laboratory	Max: Class III mod 2	LWT	Stone cast model	Direct & Indirect	Yes	3DP has less fit
Gan et al. (2018)	RCT	Dentate	No	Patient's mouth (IOS)	Direct	Yes	3DP has acceptable fit
Soltanzadeh et al. (2018)	Laboratory	Max: class III mod 1	LWT	Resin cast model	Direct	Yes	3DP has less fit, but clinically acceptable
Torii et al. (2018)	Laboratory	1st molar simulation	LWT	Tooth die model	Direct	No	No significant difference
Bajunaid et al. (2019)	Laboratory	Man: Class III mod 1	LWT	Metal cast model	Direct	Yes	3DP has better fit
Chen et al. (2019)	Laboratory	Different classes	LWT	Resin cast model	Direct	NR	3DP has less fit, but clinically acceptable
Negm, Aboutaleb & Alam-Eldein (2019)	Laboratory	Max: Class I	No	Stone cast model	Direct & Indirect	Yes	3DP has less fit
Carneiro Pereira et al. (2019)	CR	Man: Class III mod 1	No	Patient's mouth (IOS)	Indirect	Yes	3DP has acceptable fit
Tasaka et al. (2019)	Laboratory	Man: Class II mod 1	No	Cast model	Direct & Indirect	No	3DP has acceptable fit
Tregemen et al. (2019)	CT	Different classes	LWT	Patient's mouth (IOS)	Direct	Yes	3DP has better fit
Takahashi et al. (2020)	Laboratory	1st molar simulation	No	Tooth die model	Direct & Indirect	NR	3DP has acceptable fit

Tasaka et al. (2020)	Laboratory	Man: Class II mod 1	No	Plaster cast model	Direct	NR	3DP has acceptable fit
Wu et al. (2020)	CR	Man: Class I mod 1	No	Patient's mouth (IOS)	Direct	Yes	3DP has acceptable fit
Xie et al. (2020)	Laboratory	1st molar simulation	LWT	Tooth die model	Direct (0°, 45°, 90°)	Yes	3DP has better fit
Cabrita et al. (2021)	CR	Man: Class I	No	Stone cast model	Direct	Yes	3DP has acceptable fit
Peng et al. (2022)	Laboratory	Man: Class II mod 2	LWT	Cast model	Direct	NR	3DP has better fit

CT: Clinical Trial; CR: Clinical Report; RCT: Randomized Clinical Trial; LWT: Lost-Wax Technique; NR: Not Reported

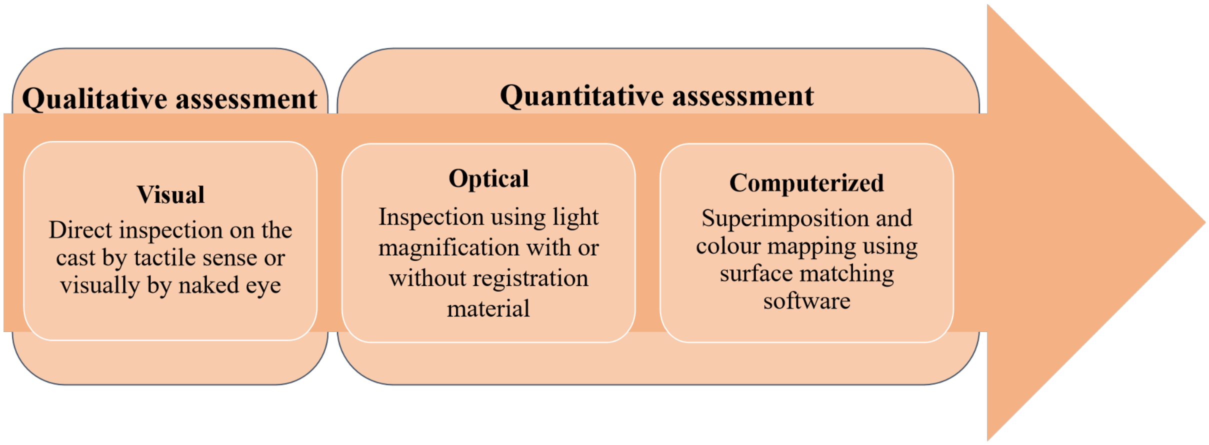

FIGURE 2. The main categories of methods used to assess the fit and accuracy of the RPD framework

OPTICAL ASSESSMENT METHOD

In this method, the adaptation of the RPD framework is measured in two dimensions, such as vertical and horizontal gaps under the RPD components as well as the internal discrepancy between the surface of the underlying tissues and different parts of RPD. Seven studies (Arnold et al. 2018; Bajunaid et al. 2019; Gan et al. 2018; Lee et al. 2017; Takahashi et al. 2020; Torii et al. 2018; Xie et al. 2020) used the optical method to assess the adaptation of the RPD framework, and one study (Ye et al. 2017) used visual and optical methods. Of these, four studies used a stereomicroscope (Gan et al. 2018; Lee et al. 2017; Xie et al. 2020; Ye et al. 2017), two studies (Takahashi et al. 2020; Torii et al. 2018) used a profile projector, one study (Bajunaid et al. 2019) used a digital microscope, and one study (Arnold et al. 2018) used a light microscope. This method assessed different measurement areas, including sections on the cast, all RPD components, three-point clasp, rest, proximal plate, and major connector. The optical assessment was performed with or without the aid of registration materials. Among the studies, three studies (Bajunaid et al. 2019; Gan et al. 2018; Ye et al. 2017) used light-bodied polyvinyl siloxane (PVS), and three others (Lee et al. 2017; Takahashi et al. 2020; Torii et al. 2018) used Fit & Bite Checker, while two studies (Arnold et al. 2018; Xie et al. 2020) did not use any registration materials.

COMPUTERIZED ASSESSMENT METHOD

This method is based on the superimposition of the standard tessellation language (STL) file of the reference to the output of the RPD at different points/areas of the framework. Nine studies (Batalha & Araújo, 2017; Chen & Guang 2012; Chen et al. 2011; Chen et al. 2019; Negm, Aboutaleb & Alam-Eldein 2019; Peng et al. 2020; Soltanzadeh et al. 2019; Tasaka et al. 2020, 2019) used

TABLE 2. Methods of assessment and related parameters used by the included studies

Study	Type of assessment	Method of assessment	Type of measurement	Area of measurement	Materials used
Eggbeer, Bibb & Williams (2005)	Qualitative	Visual inspection	Adaptation	Overall	No
Bibb et al. (2006)	Qualitative	Visual inspection	Adaptation	Overall	No
Williams et al. (2006)	Qualitative	Visual inspection	Adaptation	Overall	No
Chen et al. (2011)	Quantitative	Computerized (RAPIDFORM)	Average deviation	Overall	No
Chen & Guan (2012)	Quantitative	Computerized (RAPIDFORM)	Average deviation	Overall	No
Kattadiyil et al. (2014)	Qualitative	Visual inspection	Adaptation	Overall	No
Batalha & Araújo (2017)	Qualitative	Visual inspection	Adaptation	Overall	No
	Quantitative	Computerized (GOM Inspect)	Average deviation	Overall	
Hu, Pei & Wen (2017)	Qualitative	Visual inspection	Adaptation	Overall	No
Lee et al. (2017)	Quantitative	Optical (Stereomicroscope)	Internal discrepancy	All components	Fit & Bite Checker
Ye et al. (2017)	Qualitative	Visual inspection	Adaptation	Overall	No
	Quantitative	Optical (Stereomicroscope)	Gap distance	Different sections	PVS
Arnold et al. (2018)	Quantitative	Optical (Light microscope)	Gap distance	Clasp	No
Gan et al. (2018)	Quantitative	Optical (Stereomicroscope)	Gap distance	Major connector	PVS
Soltanzadeh et al. (2018)	Quantitative	Computerized (Geomagic)	Gap distance	All components	No
Torii et al. (2018)	Quantitative	Optical (Profile projector)	Gap distance	Rest, 3-point clasp	Fit & Bite Checker
Bajunaid et al. (2019)	Quantitative	Optical (Digital microscope)	Gap distances	Rest	PVS
Chen et al. (2019)	Quantitative	Computerized (Geomagic NX image)	Gap distance	Overall	No
Negm, Aboutaleb & Alam-Eldein (2019)	Quantitative	Computerized (Geomagic)	Gap distance	Overall	No
			Trueness	All components	No
Carneiro Pereira et al. (2019)	Qualitative	Visual inspection	Adaptation	Overall	No
Tasaka et al. (2019)	Quantitative	Computerized (GOM Inspect)	Average deviation	All components	No
Tregemen et al. (2019)	Qualitative	Visual inspection	Adaptation	Overall	Questionnaire
Takahashi et al. (2020)	Quantitative	Optical (Profile projector)	Gap distance	Clasp	Fit & Bite checker
Tasaka et al. (2020)	Quantitative	Computerized (GOM Inspect)	Average deviation	Clasp	No
Wu et al. (2020)	Qualitative	Visual inspection	Adaptation	Overall	No
Xie et al. (2020)	Quantitative	Optical (Stereomicroscope)	Gap distance	3-point clasp	No
Cabrita et al. (2021)	Qualitative	Visual inspection	Adaptation	Overall	No
Peng et al. (2022)	Quantitative	Computerized (Geomagic)	Trueness		No

the computerized method mainly by using software programs to assess the fit accuracy of the 3DP RPD framework. The measurements of the fit accuracy were performed in three dimensions, including gap distance (n = three studies), average deviation (n = five studies), and trueness (n = two studies). Only one study (Negm, Aboutaleb & Alam-Eldein 2019) used two measurement types (gap distance and trueness). Regarding the area of measurement, studies assessed the fit accuracy of the RPD components or the overall fit. Different software programs were used, including Rapidform (n = two studies), Geomagic (n = four studies), and GOM Inspect (n = three studies). Chen et al. (2019) used two different software programs (Geomagic and NX Image).

DISCUSSION

This review aimed to provide comprehensive evidence on the methods used to assess the adaptation of the additive manufactured RPDs. Initially, visual and tactile examinations were the most popular methods used to assess the fit accuracy of RPDs on a cast or in oral cavity. Clinically, the accepted RPD framework should have the following criteria: 1) all rests should be adequately seated on their rest seats, 2) all rigid elements should touch the teeth, and 3) major connector should not impinge the underlying soft tissues, and there is no visible relief space more than 1 mm (Alifui-Segbaya et al. 2017). Unfortunately, a visual inspection will not give precise quantitative measurements. In addition, the results of visual and tactile assessments are solely dependent on the investigator's clinical judgment, which may vary according to personal evaluation (Al Mortadi, Alzoubi & Williams 2020). However, when good training and calibration of a clinician is conducted before the visual examination, the result of evaluation can be more reliable and acceptable (Tregerman et al. 2019).

The optical assessment utilizes optical instruments such as light microscope or stereomicroscope that can provide more accurate fit measurements in comparison to the visual method. Optical assessment can be performed with or without registration materials that will register the gap between RPD framework and the opposing surface either *in-vivo* or *in-vitro.* Many materials were used for this purpose, such as PVS (Bajunaid et al. 2019; Gan et al. 2018; Ye et al. 2017), Fit & Bite Checker (Lee et al. 2017; Takahashi et al. 2020; Torii et al. 2018), and radiopaque fit testing material (Oka et al. 2016). The drawbacks of optical assessment are the difficulty of specifying the exact measurement sites and the fact that it does not reflect the overall fit of the framework. In addition, the amount of space that is being evaluated by measuring the thickness of the silicone registration materials may not be accurate due to distortion and tearing of the material following its removal from the mouth (Stern et al. 1985). Some studies combined both visual and optical fit assessments to acquire better fit assessments.

With the development of digital technology, computer-based software facilitates a precise evaluation of RPD fitting by determining the best possible fit of the RPD framework with the opposing surface at different sites. It creates a virtual colour map with different colours indicating different amounts of fit. The implementation of colour mapping enables clinician to identify over-pressed or misfit areas in more than 500 points (Baig, Tan & Nicholls 2010; Chen et al. 2011; Rudd & Rudd 2001). This method offers a significant improvement in the number of comparison points as opposed to the optical methods (Al Mortadi, Alzoubi & Williams 2020; Baig, Tan & Nicholls 2010). Furthermore, superimposition of a 3D fabricated RPD with the original CAD data provides information on the amount of dimensional discrepancy, trueness, and accuracy of the printing procedure both qualitatively and quantitatively.

In order to assess the overall accuracy of a 3D-printed RPD, it is recommended to use a virtual superimposition of the original CAD design and the 3D-printed RPD using special surface matching software, and the average deviation is recorded. The deviation can be measured as minimum, maximum, and average deviation. Only one study (Tregerman et al. 2019) used the root mean square (RMS) to indicate the amount of trueness of 3DP RPD. RMS is a good measure of accuracy to compare prediction errors of different models or model configurations for a particular variable and not between variables, as it is scale-dependent (Hodson 2022). Most of the included studies showed a low average deviation which indicated high trueness for the 3DP RPD, indicating that the accuracy of 3DP RPD is promising and can be clinically accepted. The high trueness average of 3DP RPD may be contributed to the reduction of lab error and decreased inter-operator variability (Alharbi, Wismeijer & Osman 2017; Bajunaid et al. 2019; Peng et al. 2020). According to the data presented in this review, the evidence shows that in the last three years, the application of software-based methods in assessing the fit of RPDs yields more accurate and reliable outcomes, either laboratory or clinically.

A novel fit-testing method for dental prostheses using a combination of silicone replica technique and micro-computed tomography (μCT) was proposed by Oka et al. (2016). This method can be employed during the try-in stage to enable an accurate and non-invasive evaluation of the fit. Interestingly, even though this method was proposed in 2016, none of the included studies has used it to evaluate fit of RPD frameworks which most likely due to the cost of using CT scans and the availability of the novel contrast agent.

Various studies in this review showed promising results of RPDs fit and accuracy when fabricated with 3D-printing techniques, while other studies demonstrated less fit and more dimensional discrepancy in 3DP frameworks. The different outcomes may be attributed by the diverse protocols used during the 3D-printing procedure, such as different light intensity, printing direction, thickness and number of the building layers, the amount of supporting material, and the post-processing heat treatment (Gan et al. 2018; Xie et al. 2020). In addition, different polishing procedures may also affect the outcome (Brudvik & Reimers 1992).

It was reported that the polishing procedure could influence the fit accuracy, especially on the intaglio surface of the rest component of the framework (Rudd & Rudd 2001). Stern et al. (1985) suggested that careful finishing and polishing procedures may increase fit precision, and excessive finishing may result in unnecessary metal removal from the internal surface. Brudvik and Reimers (1992) described an average of 127 μm of metal loss from the surface of the Co-Cr framework after finishing and polishing. Sandblasting and polishing should be performed carefully to decrease the effect on the intimate fit of the RPD framework (Rudd & Rudd 2001). Findings from our review showed conflicting results of fit of the 3DP RPD when different finishing and polishing protocols were used. To the best of our knowledge, there are no studies that have described the best polishing protocol on the fit of 3DP RPD frameworks. Therefore, further investigation should be carried out to evaluate the influence of polishing on the discrepancy of digitally fabricated framework.

The number of available clinical trials that have evaluated the method of fit assessment of 3DP RPD is limited. We believe the reasons are due to the high cost of 3D printing and the requirement of post-processing. As a result, the sample sizes in most studies are relatively small. Well-conducted clinical trials are essential to evaluate the long-term impact of different factors on fit and accuracy of the additive-manufactured RPDs.

CONCLUSIONS

Based on the finding of this review, the following conclusions can be drawn: The fit of the additive-manufactured RPD can be carried out by visual, optical, and computerized assessment. Computerized assessment through surface matching software can detect minute misfits and dimensional changes that cannot be detected visually. It can provide an accurate and precise quantitative assessment of denture fit, which facilitates identification of over-pressed or misfit areas upon insertion of 3D-printed RPDs. Thus, desirable modifications can be carried out before denture insertion.

REFERENCES

Academy of Prosthodontics. 1995. Principles, concepts, and practices in prosthodontics. *J. Prosthet. Dent.* 73(1): 73-94. doi: 10.1016/s0022-3913(05)80276-8

Ahmed, N., Abbasi, M.S., Haider, S., Ahmed, N., Habib, S.R., Altamash, S., Zafar, M.S. & Alam, M.K. 2021. Fit accuracy of removable partial denture frameworks fabricated with CAD/CAM, rapid prototyping, and conventional techniques: A systematic review. *Biomed. Res. Int.* 2021: 3194433. doi: 10.1155/2021/3194433

Al Mortadi, N., Alzoubi, K.H. & Williams, R. 2020. A scoping review on the accuracy of fit of removable partial dentures in a developing digital context. *Clin. Cosmet. Investig. Dent.* 12: 551-562. doi: 10.2147/ccide.S282300

Alharbi, N., Wismeijer, D. & Osman, R.B. 2017. Additive manufacturing techniques in prosthodontics: Where do we currently stand? A critical review. *Int. J. Prosthodont.* 30(5): 474-484. doi: 10.11607/ijp.5079

Alifui-Segbaya, F., Williams, R.J. & George, R. 2017. Additive manufacturing: A novel method for fabricating cobalt-chromium removable partial denture frameworks. *Eur. J. Prosthodont. Restor. Dent.* 25(2): 73-78. doi: 10.1922/EJPRD_1598Alifui-Segbaya06

Almufleh, B., Emami, E., Alageel, O., de Melo, F., Seng, F., Caron, E., Nader, S.A., Al-Hashedi, A., Albuquerque, R., Feine, J. & Tamimi, F. 2018. Patient satisfaction with laser-sintered removable partial dentures: A crossover pilot clinical trial. *J. Prosthet. Dent.* 119(4): 560-567.e1. doi: 10.1016/j.prosdent.2017.04.021

Arnold, C., Hey, J., Schweyen, R. & Setz, J.M. 2018. Accuracy of CAD-CAM-fabricated removable partial dentures. *J. Prosthet. Dent.* 119(4): 586-592. doi: 10.1016/j.prosdent.2017.04.017

Azari, A. & Nikzad, S. 2009. The evolution of rapid prototyping in dentistry: A review. *Rapid Prototyping Journal* 15(3): 216-225. doi: 10.1108/13552540910961946

Baig, M.R., Tan, K.B. & Nicholls, J.I. 2010. Evaluation of the marginal fit of a zirconia ceramic computer-aided machined (CAM) crown system. *J. Prosthet. Dent.* 104(4): 216-27. doi: 10.1016/s0022-3913(10)60128-x

Bajunaid, S.O., Altwaim, B., Alhassan, M. & Alammari, R. 2019. The fit accuracy of removable partial denture metal frameworks using conventional and 3D printed techniques: An *in vitro* study. *J. Contemp. Dent. Pract.* 20(4): 476-481.

Batalha, A.E.F. & Araújo, R.M. 2017. Development of removable partial dentures by using additive manufacture and casting processes. *Archives of Materials Science and Engineering* 87(1): 33-40.

Bibb, R., Eggbeer, D. & Williams, R. 2006. Rapid manufacture of removable partial denture frameworks. *Rapid Prototyping Journal* 12(2): 95-99. doi: 10.1108/13552540610652438

British Society for the Study of Prosthetic Dentistry. 1981. Guides to standards in prosthetic dentistry. A report by the British Society for the study of prosthetic dentistry. *Br. Dent. J.* 150(6): 167-169. doi: 10.1038/sj.bdj.4804565

Brudvik, J.S. & Reimers, D. 1992. The tooth-removable partial denture interface. *J. Prosthet. Dent.* 68(6): 924-927. doi: 10.1016/0022-3913(92)90552-l

Cabrita, J.P., Mendes, T.A., Martins, J.P. & Lopes, L.P. 2021. Removable partial denture metal framework manufactured by selective laser melting technology - A clinical report. *Revista Portuguesa de Estomatologia, Medicina Dentária e Cirurgia Maxilofacial* 62(2): 109-113.

Campbell, S.D., Cooper, L., Craddock, H., Hyde, T.P., Nattress, B., Pavitt, S.H. & Seymour, D.W. 2017. Removable partial dentures: The clinical need for innovation. *J. Prosthet. Dent.* 118(3): 273-280. doi: 10.1016/j.prosdent.2017.01.008

Carneiro Pereira, A.L., Martins de Aquino, L.M., Carvalho Porto de Freitas, R.F., Soares Paiva Tôrres, A.C. & da Fonte Porto Carreiro, A. 2019. CAD/CAM-fabricated removable partial dentures: A case report. *Int. J. Comput. Dent.* 22(4): 371-379.

Chen, G.X. & Guang, K. 2012. Research of metallic part fabrication by selective laser melting. *Applied Mechanics and Materials* 120: 284-287. doi: 10.4028/www.scientific.net/AMM.120.284

Chen, G.X., Zeng, X.Y., Wang, Z.M., Guan, K. & Peng, C.W. 2011. Fabrication of removable partial denture framework by selective laser melting. *Advanced Materials Research* 317-319: 174-178. doi: 10.4028/www.scientific.net/AMR.317-319.174

Chen, H., Li, H., Zhao, Y., Zhang, X., Wang, Y. & Lyu, P. 2019. Adaptation of removable partial denture frameworks fabricated by selective laser melting. *J. Prosthet. Dent.* 122(3): 316-324. doi: 10.1016/j.prosdent.2018.11.010

Dunham, D., Brudvik, J.S., Morris, W.J., Plummer, K.D. & Cameron, S.M. 2006. A clinical investigation of the fit of removable partial dental prosthesis clasp assemblies. *J. Prosthet. Dent.* 95(4): 323-326. doi: 10.1016/j.prosdent.2006.02.001

Eggbeer, D., Bibb, R. & Williams, R. 2005. The computer-aided design and rapid prototyping fabrication of removable partial denture frameworks. *Proc. Inst. Mech. Eng. H.* 219(3): 195-202. doi: 10.1243/095441105x9372

Fenlon, M.R., Juszczyk, A.S., Hughes, R.J., Walter, J.D. & Sherriff, M. 1993. Accuracy of fit of cobalt-chromium removable partial denture frameworks on master casts. *Eur. J. Prosthodont. Restor. Dent.* 1(3): 127-130.

Frank, R.P., Brudvik, J.S., Leroux, B., Milgrom, P. & Hawkins, N. 2000. Relationship between the standards of removable partial denture construction, clinical acceptability, and patient satisfaction. *J. Prosthet. Dent.* 83(5): 521-527. doi: 10.1016/s0022-3913(00)70008-4

Gan, N., Ruan, Y., Sun, J., Xiong, Y. & Jiao, T. 2018. Comparison of adaptation between the major connectors fabricated from intraoral digital impressions and extraoral digital impressions. *Sci. Rep.* 8(1): 529. doi: 10.1038/s41598-017-17839-4

Hodson, T.O. 2022. Root mean square error (RMSE) or mean absolute error (MAE): When to use them or not. *Geoscientific Model Development Discussions* 15(14): 5481-5487.

Hu, F., Pei, Z. & Wen, Y. 2019. Using intraoral scanning technology for three-dimensional printing of Kennedy Class I removable partial denture metal framework: A clinical report. *J. Prosthodont.* 28(2): e473-e476. doi: 10.1111/jopr.12712

International Organization for Standardization. 1998. *Accuracy (Trueness and Precision) of Measurement Methods and Results - Part 1: General Principles and Definitions - Technical Corrigendum 1.* Geneva, Switzerland: International Organization for Standardization.

Kattadiyil, M.T., Mursic, Z., AlRumaih, H. & Goodacre, C.J. 2014. Intraoral scanning of hard and soft tissues for partial removable dental prosthesis fabrication. *J. Prosthet. Dent.* 112(3): 444-448. doi: 10.1016/j.prosdent.2014.03.022

Lang, L.A. & Tulunoglu, I. 2014. A critically appraised topic review of computer-aided design/computer-aided machining of removable partial denture frameworks. *Dent. Clin. North Am.* 58(1): 247-255. doi: 10.1016/j.cden.2013.09.006

Lee, J.W., Park, J.M., Park, E.J., Heo, S.J., Koak, J.Y. & Kim, S.K. 2017. Accuracy of a digital removable partial denture fabricated by casting a rapid prototyped pattern: A clinical study. *J. Prosthet. Dent.* 118(4): 468-474. doi: 10.1016/j.prosdent.2016.12.007

Mai, H.Y., Mai, H.N., Kim, H.J., Lee, J. & Lee, D.H. 2022. Accuracy of removable partial denture metal frameworks fabricated by computer-aided design/computer-aided manufacturing method: A systematic review and meta-analysis. *J. Evid. Based Dent. Pract.* 22(3): 101681. doi: 10.1016/j.jebdp.2021.101681

Mendes, T.A., Marques, D., Lopes, L.P. & Caramês, J. 2019. Total digital workflow in the fabrication of a partial removable dental prostheses: A case report. *SAGE Open Med. Case Rep.* 7: 2050313x19871131. doi: 10.1177/2050313x19871131

Negm, E.E., Aboutaleb, F.A. & Alam-Eldein, A.M. 2019. Virtual evaluation of the accuracy of fit and trueness in maxillary poly(etheretherketone) removable partial denture frameworks fabricated by direct and indirect CAD/CAM techniques. *J. Prosthodont.* 28(7): 804-810. doi: 10.1111/jopr.13075

Oka, Y., Sasaki, J., Wakabayashi, K., Nakano, Y., Okamura, S.Y., Nakamura, T., Imazato, S. & Yatani, H. 2016. Fabrication of a radiopaque fit-testing material to evaluate the three-dimensional accuracy of dental prostheses. *Dent. Mater.* 32(7): 921-928. doi: 10.1016/j.dental.2016.03.011

Peng, P-W., Hsu, C-Y., Huang, H-Y., Chao, J-C. & Lee, W-F. 2020. Trueness of removable partial denture frameworks additively manufactured with selective laser melting. *J. Prosthet. Dent*. 127(1): 122-127.

Preshaw, P.M., Walls, A.W., Jakubovics, N.S., Moynihan, P.J., Jepson, N.J. & Loewy, Z. 2011. Association of removable partial denture use with oral and systemic health. *J. Dent.* 39(11): 711-719. doi: 10.1016/j.jdent.2011.08.018

Rudd, R.W. & Rudd, K.D. 2001. A review of 243 errors possible during the fabrication of a removable partial denture: Part I. *J. Prosthet. Dent.* 86(3): 251-261. doi: 10.1067/mpr.2001.118021

Soltanzadeh, P., Suprono, M.S., Kattadiyil, M.T., Goodacre, C. & Gregorius, W. 2019. An *in vitro* investigation of accuracy and fit of conventional and CAD/CAM removable partial denture frameworks. *J. Prosthodont.* 28(5): 547-555. doi: 10.1111/jopr.12997

Stern, M.A., Brudvik, J.S. & Frank, R.P. 1985. Clinical evaluation of removable partial denture rest seat adaptation. *J. Prosthet. Dent.* 53(5): 658-662. doi: 10.1016/0022-3913(85)90015-0

Takahashi, K., Torii, M., Nakata, T., Kawamura, N., Shimpo, H. & Ohkubo, C. 2020. Fitness accuracy and retentive forces of additive manufactured titanium clasp. *Journal of Prosthodontic Research* 64(4): 468-477.

Tasaka, A., Kato, Y., Odaka, K., Matsunaga, S., Goto, T.K., Abe, S. & Yamashita, S. 2019. Accuracy of clasps fabricated with three different CAD/CAM technologies: Casting, milling, and selective laser sintering. *Int. J. Prosthodont.* 32(6): 526-529. doi: 10.11607/ijp.6363

Tasaka, A., Shimizu, T., Kato, Y., Okano, H., Ida, Y., Higuchi, S. & Yamashita, S. 2020. Accuracy of removable partial denture framework fabricated by casting with a 3D printed pattern and selective laser sintering. *Journal of Prosthodontic Research* 64(2): 224-230.

Torabi, K., Farjood, E. & Hamedani, S. 2015. Rapid prototyping technologies and their applications in prosthodontics, a review of literature. *J. Dent. (Shiraz)* 16(1): 1-9.

Torii, M., Nakata, T., Takahashi, K., Kawamura, N., Shimpo, H. & Ohkubo, C. 2018. Fitness and retentive force of cobalt-chromium alloy clasps fabricated with repeated laser sintering and milling. *J. Prosthodont. Res.* 62(3): 342-346. doi: 10.1016/j.jpor.2018.01.001

Tregerman, I., Renne, W., Kelly, A. & Wilson, D. 2019. Evaluation of removable partial denture frameworks fabricated using 3 different techniques. *J. Prosthet. Dent.* 122(4): 390-395. doi: 10.1016/j.prosdent.2018.10.013

Tricco, A.C., Lillie, E., Zarin, W., O'Brien, K.K., Colquhoun, H., Levac, D., Moher, D., Peters, M.D.J., Horsley, T., Weeks, L., Hempel, S., Akl, E.A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M.G., Garritty, C., Lewin, S., Godfrey, C.M., Macdonald, M.T., Langlois, E.V., Soares-Weiser, K., Moriarty, J., Clifford, T., Tunçalp, Ö. & Straus, S.E. 2018. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Ann. Intern. Med.* 169(7): 467-473. doi: 10.7326/m18-0850

Williams, R.J., Bibb, R., Eggbeer, D. & Collis, J. 2006. Use of CAD/CAM technology to fabricate a removable partial denture framework. *J. Prosthet. Dent.* 96(2): 96-99. doi: 10.1016/j.prosdent.2006.05.029

Wu, J., Li, Y. & Zhang, Y. 2017. Use of intraoral scanning and 3-dimensional printing in the fabrication of a removable partial denture for a patient with limited mouth opening. *J. Am. Dent. Assoc.* 148(5): 338-341. doi: 10.1016/j.adaj.2017.01.022

Xie, W., Zheng, M., Wang, J. & Li, X. 2020. The effect of build orientation on the microstructure and properties of selective laser melting Ti-6Al-4V for removable partial denture clasps. *J. Prosthet. Dent.* 123(1): 163-172. doi: 10.1016/j.prosdent.2018.12.007

Ye, H., Ning, J., Li, M., Niu, L., Yang, J., Sun, Y. & Zhou, Y. 2017. Preliminary clinical application of removable partial denture frameworks fabricated using computer-aided design and rapid prototyping techniques. *Int. J. Prosthodont.* 30(4): 348-353. doi: 10.11607/ijp.5270

*Corresponding author; email: nosizana@um.edu.my