Original Article

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Dentistry Section

Comparing Minor Connector Castability of Printed Cast Partial Dentures to Conventional Cast Partial Dentures: An In-vitro Study

MEGHNA BUDATI[1], SURESH VENUGOPALAN[2]

ABSTRACT

Introduction: Partial denture prostheses are used to restore missing teeth and oral function, with minor connectors playing a crucial role in the denture framework. Traditionally, Cast Partial Dentures (CPD) are made using wax patterns and metal casting; however, this process can sometimes result in issues such as porosity or distortion. Advances in digital dentistry have introduced 3D printing, which offers a new method for creating denture frameworks with greater precision. However, the impact of 3D printing on the castability of minor connectors compared to conventional methods remains underexplored.

Aim: To compare the minor connector castability of manually CPDs to Direct Metal Laser Sintering (DMLS) printed partial dentures. Key objectives include assessing the minor connector castability between the two groups, manual and DMLS, before and after wax-up and casting.

Materials and Methods: This in-vitro study was conducted in the Department of Prosthodontics at Saveetha Dental College, Chennai, Tamil Nadu, India from July 2023 to December 2023. A total of 10 samples were included and divided into two groups. Group 1 consisted of five samples of manually CPDs, while group 2 included five samples of DMLS printed partial dentures. A standardised casting procedure was followed for both the manually cast and DMLS printed partial dentures to evaluate their minor connector castability. The two groups were compared for wax-up and casting. To assess castability, the number of lattice framework holes in each connector was counted after wax-up and fabrication. Statistical analysis was performed using a statistical software program Statistical Package for Social Sciences (SPSS) version 23.0. The Wilcoxon signed-rank test, a non parametric test, was used, with statistical significance set at $p<0.05$.

Results: Comparisons between the groups revealed a statistically significant difference in the medians of manual wax-up ($p=0.25$) and casting compared to DMLS ($p=0.317$) design and printing. The DMLS group demonstrated superior accuracy compared to manual casting.

Conclusion: The present study demonstrates that the Removable Partial Denture (RPD) frameworks designed and produced by DMLS exhibit better castability compared to manual wax-up and casting.

Keywords: Computer-aided design, Dental casting technique, Direct metal laser sintering, Sintering

INTRODUCTION

Metal frameworks for RPDs are increasingly being fabricated using Computer-aided Design and Computer-Aided Manufacturing (CAD/CAM) technology [1]. Traditionally, the procedure for designing a Removable Partial Denture (RPD) involved creating dental stone models, evaluating and characterising the teeth and soft tissues around the placement path, and meticulously creating the RPD framework using a direct waxing process [2]. Nonetheless, the fabrication of many dental restorations has been made easier by the increasing popularity of CAD/CAM [3]. With the help of additive manufacturing technology, the CAD/CAM method for creating RPD frameworks has gotten underway [4,5].

The fabrication of digital patterns of the RPD frameworks and the ability to digitally survey the cast to identify desired and undesirable undercuts are two important advantages of employing CAD/CAM and 3D printing technology in the fabrication of RPDs [6,7]. A standard digital workflow usually includes obtaining a computer-generated image of the oral hard and soft tissues. Either an intraoral digital scan or a stone cast that has been digitally scanned in a lab can be used for this. Depending on their depth along the designated line of insertion, undercuts are color-coded. After that, the virtual block-outs are automatically identified and displayed on the virtual cast. The design of the main connector and retention grid is completed before that of the clasps and rests [8,9]. After the design is finished, the CAD software will digitally export the created RPD framework as a Standard Triangulation Language (STL) file. The STL file may be used to manufacture the RPD framework additively or subtractively [10]. Depending on the method of fabrication, a definitive prosthesis can be manufactured directly from the computer design or from an intermediate product like a resin-elimination pattern that will be invested and cast [11]. These new digital workflows might be useful in place of the conventional waxing and investing process, which can lead to castings with poor fit due to various causes such as refractory cast distortion and wax pattern distortion [12,13].

The DMLS printing is a technique for creating CPDs that has evolved with the development of digital dentistry. DMLS is a digital process that combines CAD and CAM to build dental prostheses. The structure of the CPD is constructed progressively using layers of metal powder that are fused together by a laser in a DMLS printer [14].

The CPDs have many components, but minor connectors are the ones that connect different partial denture framework components to the major connector, requiring them to be fabricated in small, precise dimensions. Hence, reproducibility of these components is essential in the final denture framework [15]. However, there is a gap in the literature regarding this aspect. Previous studies have primarily focused on assessing the castability of major connectors and clasps, emphasising their fit, adaptation, and dimensional accuracy due to their critical roles in stability and retention. Limited research has specifically addressed the castability of minor connectors [16,17].

Despite their smaller dimensions, minor connectors play a pivotal role in framework integration and functionality. Precise fabrication ensures compatibility with the major connector and other components; yet, the challenges of achieving this precision remain underexplored. Therefore, the aim of present study is to compare the minor connector castability of manually fabricated CPDs to that of DMLS printed CPDs. According to the null hypothesis, there is no difference in the minor connector castability between manually CPDs and DMLS printed CPDs.

MATERIALS AND METHODS

This in-vitro study was conducted in the Department of Prosthodontics at Saveetha Dental College, Chennai, Tamil Nadu, India from July 2023 to December 2023. Ethical approval for the research was obtained from the Institutional Systematic Review Board (Approval number: SRB/SDC/PROSTHO-2206/23/177).

The study included a total of 10 samples divided into two groups: Group 1 consisted of five samples of manually fabricated CPDs, while Group 2 comprised five samples of DMLS fabricated CPDs.

Sample size calculation: The sample size was calculated (n=10) using G* Power 3.1.9.3 for Mac OS X, with a power of 0.095, based on data from a previously published study [18].

Inclusion criteria:

- Maxillary Kennedy Class-III partially edentulous casts with modification 1.
- Prepared abutments with six rest seats: 17 mesial, 16 distal, 13 cingulum, 23 cingulum, 24 distal, and 27 mesial.
- Type-IV dental stone models designed for CPDs.

Exclusion criteria:

- Casts with anatomical defects, distortions, or irregularities.
- Models with incomplete rest seat preparations or guiding plane adjustments.

Study Procedure

Model preparation: An ideal partially edentulous maxillary cast with Kennedy Class-III and modification 1 was fabricated using Type-IV dental stone. Rest seat preparations were performed using a high-speed rotary handpiece to achieve the required dimensions. Parallel guiding planes were adjusted, and the casts were duplicated using silicone duplicating material.

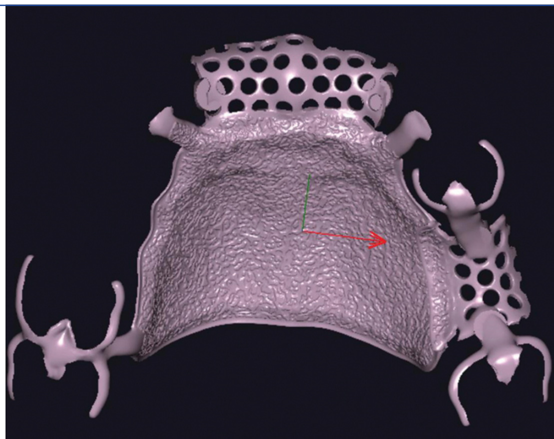
Group 1 (Manual fabrication): The reference model was blocked out and duplicated using a silicone-based duplicating material, which was then poured with Type-IV dental stone. Wax patterns for clasps, major connectors, minor connectors, and other framework components were fabricated manually. The wax patterns were invested using phosphate-bonded investment material and cast using the lost wax technique with Cobalt-Chromium (Co-Cr) alloy at 1240°C (2265°F). The casting was retrieved, cooled, and sandblasted with medium-grit (50 μm) aluminum oxide [Table/Fig-1,2].

Group 2 (DMLS fabrication): Five stone casts were prepared using Type-IV scannable dental stone. Each cast was scanned using a 3Shape E4 extraoral scanner. A digital RPD framework was designed using 3Shape software, incorporating precise measurements for rests (2.0 mm), major connectors (4.0 mm), proximal plates (3.0 mm), reciprocation plates or clasps (3.0 mm), and the origin of the retentive arms (2.0 mm) [19]. The frameworks were fabricated using DMLS printing with Co-Cr alloy. [Table/Fig-3,4].

Assessment of castability: The mesh grid minor connector design satisfies the previously mentioned criteria and facilitates the simple visualisation and assessment of the casting [20]. The mesh grid minor connector design was used to evaluate castability, a method proposed by Whitlock RP et al., [21]. The castability percentage was calculated by counting the number of fully cast lattice framework holes before and after fabrication. This method offers a quick, visual,

[Table/Fig-1]: Wax pattern for manual casting.

[Table/Fig-2]: Cast Partial Denture (CPD) after finishing and polishing.



[Table/Fig-3]: Digital design.

[Table/Fig-4]: DMLS printed CPD framework.

and quantitative assessment of alloy reproducibility in both manual and DMLS techniques.

STATISTICAL ANALYSIS

The statistical analysis was carried out using SPSS Software (IBM Corp., 2011). IBM SPSS Statistics for Windows, version 23.0 (Armonk, NY: IBM Corp.) was utilised. The Shapiro-Wilk test was performed to assess the normality of the data, and the Wilcoxon signed-rank test was employed for statistical analysis. A significance level of p<0.05 was considered for all statistical tests.

Groups	Mean	95% Confidence interval		Standard deviation	Standard error	p-value
		Lower bound	Upper bound			
Manual wax-up	17	16.245	17.754	1.054	0.333	0.025*
Manual casting	16.5	16.123	16.877	0.527	0.166	
DMLS design	22.5	18.352	26.647	5.797	1.833	0.317
DMLS printing	22.4	18.322	26.388	5.699	1.802	

[Table/Fig-5]: Descriptive statistics and p-values for minor connector castability across groups.
Wilcoxon signed-rank test, *p<0.05: statistically significant

RESULTS

All areas (anterior and posterior meshwork) of each sample in each group were analysed and compared. The manual methods (wax-up and casting) were compared with the DMLS techniques (design and printing). The descriptive data across all groups, as shown in [Table/Fig-5], revealed distinct trends in lattice framework holes.

For Group 1 (Manual casting), a statistically significant difference (p=0.025) was observed in the number of lattice framework holes between manual wax-up (17±1.054) and manual casting (16.5±0.527). The Wilcoxon signed-rank Test showed that the median of differences was not equal to zero, leading to the rejection of the null hypothesis. The reduction in the number of mesh holes during manual casting can be attributed to potential errors in the casting process, such as incomplete flow of molten metal or defects in the wax pattern.

In contrast, for Group 2 (DMLS printing), the difference between DMLS design (22.5±5.797) and DMLS printing (22.4±5.699) was not statistically significant (p=0.317). The Wilcoxon signed-rank Test indicated that the median of differences was equal to zero, supporting the null hypothesis. The similarity between design and printing outcomes reflects the high precision and reproducibility of DMLS technology, with only minimal discrepancies likely due to machine calibration or material flow during printing.

The intergroup analysis using the Mann's-Whitney U test reveals distinct findings. For the wax-up and design groups, the p-value of 0.063 indicates no statistically significant difference (p>0.05). However, a significant difference is observed between the casting and printing groups, with a p-value of 0.003 (p<0.05). This indicates that DMLS printing demonstrates significantly better results compared to traditional manual casting methods [Table/Fig-6].

Groups	Z-factor	p-value
Wax-up-design	-1.949	0.063
Casting-printing	-3.06	0.003*

[Table/Fig-6]: Intergroup analysis of castability using Mann's-Whitney U test.
Mann's-Whitney U test, *p<0.05: statistically significant

DISCUSSION

The present in-vitro study compared the castability of minor connectors in manual CPDs and DMLS-printed frameworks. The null hypothesis was rejected, indicating a significant difference in castability between the manual wax-up and casting processes, while it was retained for the DMLS design and printing processes, indicating no significant difference. The findings revealed a statistically significant difference in the median number of mesh grid segments before and after fabrication in the manual group (p=0.025), suggesting variability in the manual casting process. In contrast, the DMLS group showed no statistically significant difference between the digital design and the printed framework (p=0.317), suggesting high reproducibility in the additive manufacturing method [Table/Fig-2].

Studies have shown that manual casting relies heavily on the lost wax process, where the accuracy of the wax pattern and the quality of the investment material are critical [13,22]. Factors such as sprue attachment design, alloy shrinkage, and gas entrapment during solidification significantly affect castability and can contribute to porosity [23,24]. Research has demonstrated that constricted sprue attachments improve castability by increasing the velocity of molten alloy entry, whereas abrupt designs often result in greater porosity [18,25]. In present study, the manual group exhibited reduced mesh grid segments post-casting, consistent with findings that porosity and alloy shrinkage often impair the castability of Co-Cr alloys [26,27]. In contrast, the absence of statistically significant differences between DMLS design and printing underscores the precision and reproducibility of DMLS technology. These findings align with additive manufacturing utilising a layer-by-layer approach guided by CAD/CAM software, ensuring precision and minimising human error [28]. Unlike manual casting, DMLS bypasses complex processes such as wax pattern creation and investment burnout, leading to fewer porosities and greater dimensional accuracy [29,30]. The present study aligns with prior research conducted by Chaturvedi S et al., which showed that DMLS frameworks consistently outperform traditional casting in terms of reproducibility and fit [17]. Additionally, the controlled heating and cooling cycles of DMLS reduce the risk of porosity and deformation, providing a cleaner and more efficient fabrication process [31].

Limitation(s)

The study's limitations include a focus on minor connectors, which restricts the generalisability of the findings. This in-vitro study specifically focused on the Kennedy Class-II modification 1 design, and the results may not fully apply to other RPD classifications or designs, such as Kennedy Class-I or Class-III modifications, which could present different challenges in castability and performance. Future research should evaluate additional RPD components, such as major connectors and clasps, for a more comprehensive assessment of castability. Expanding the study to include other RPD classifications beyond Kennedy Class-II modification 1 would further enhance the applicability of the results. Long-term clinical trials assessing the durability and performance of DMLS frameworks in-vivo are also necessary to validate these in-vitro findings.

CONCLUSION(S)

The study demonstrates how DMLS can be used to design and create a RPD framework that is clinically acceptable and shows better minor connector castability compared to the manual or conventional method of wax-up and casting. Future research could involve larger sample sizes to validate the findings across a broader population and explore various Kennedy classifications to assess how different partial denture designs impact the performance of printed versus conventional methods. This would help determine the generalisability and adaptability of 3D printing technology in diverse clinical scenarios.

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PARTICULARS OF CONTRIBUTORS:
1. Postgraduate Student, Department of Prosthodontics and Implantology, Saveetha Dental College, Chennai, Tamil Nadu, India.
2. Professor, Department of Prosthodontics and Implantology, Saveetha Dental College, Chennai, Tamil Nadu, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Suresh Venugopalan,
Professor, Department of Prosthodontics and Implantology, Saveetha Dental College, 162, Poonamallee High Road, Velappanchavadi, Chennai-600077, Tamil Nadu, India.
E-mail: suresh@saveetha.com

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