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In vitro evaluation of the dimensional accuracy of total single-unit provisional crowns produced by digital workflow

Estudo in vitro avaliativo da acurácia dimensional de coroas totais unitárias provisórias produzidas pelo método digital

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ABSTRACT

Objective: This in vitro study aims to digitally analyze and compare the accuracy of single-unit provisional crowns produced through digital workflows, using both subtractive (milling) and additive (3D printing) methods. The analysis employs image overlay methods and area calculations. **Material and Methods:** To conduct the research, a total crown preparation was performed on a dental mannequin for tooth 26, using the silhouette technique. After scanning the preparation, a provisional single-unit crown was designed using 3D CAD software, resulting in the production of 30 crowns: 15 milled and 15 printed. All specimens were scanned and analyzed using specialized 3D image software. Measurements were focused on the internal and marginal areas of the crowns, with a total of 30 measurements for the internal area and 120 for the marginal area. The original design, projected in 3D CAD software, served as the reference. Statistical analysis, including independent samples t-tests, Shapiro-Wilk normality tests, and descriptive statistics, was applied to all collected data. **Results:** Regarding the internal area, there was a statistically significant difference when comparing groups P (printed) and M (milled). Group P showed higher discrepancies compared to group M. **Conclusion:** Milled provisional crowns demonstrated higher accuracy and fidelity to the original design projected in 3D software compared to 3D printed crowns in both areas of analysis.

KEYWORDS

Crowns; Digital Technology; Printing Three-dimensional; Workflow; Computer-Aided design.

RESUMO

Objetivo: Este estudo in vitro tem como objetivo analisar e comparar digitalmente a precisão das coroas provisórias unitárias produzidas por meio de fluxo de trabalho digital, utilizando métodos tanto subtrativos (fresagem) quanto aditivos (impressão 3D). A análise emprega métodos de sobreposição de imagens e cálculos de área. **Material e Métodos:** Para conduzir a pesquisa, um preparo para coroa total foi realizada em um manequim dentário para o dente 26, usando a técnica de silhueta. Após a digitalização do preparo, uma coroa provisória unitária foi projetada usando software CAD 3D, resultando na produção de 30 coroas: 15 fresadas e 15 impressas. Todas as amostras foram digitalizadas e analisadas usando software especializado em imagens 3D. As medições foram focadas nas áreas interna e marginal das coroas, com um total de 30 medições para a área interna e 120 para a área marginal. O design original, projetado no software CAD 3D, serviu como referência. A análise estatística, incluindo testes t para amostras independentes, testes de normalidade de Shapiro-Wilk e estatísticas descritivas, foi aplicada a todos os dados coletados. **Resultados:** em relação à área interna, houve diferença estatisticamente significante quando comparados os grupos P (impresso) e M (fresado). O grupo P apresentou maiores discrepâncias em relação ao grupo M. **Conclusão:** As coroas provisórias fresadas demonstraram maior precisão e fidelidade ao design original projetado no software 3D em comparação com as coroas impressas em ambas as áreas de análise.

PALAVRAS-CHAVE

Coroas dentárias; Tecnologia digital; Impressão tridimensional; Fluxo de trabalho; Desenho assistido por computador.

INTRODUCTION

Dental prosthesis is the dental specialty responsible for the artificial replacement of one or more dental elements, often including the total replacement of teeth, in addition to their associated structures. It is traditionally divided into two large groups: removable dental prosthetics and fixed dental prosthetics.

In general, fixed prosthesis can be defined as any type of piece that is firmly fixed to a natural tooth, or one or more implants and that cannot be removed by the patient [1]. The main types include inlay, onlay, overlay, dental crown, fixed complete denture, and fixed partial denture (fixed bridge). Regardless of the type of fixed prosthesis work, a provisional restoration is necessary to aid in creating the final prosthesis.

It is through the provisional piece that we determine important factors for the success of the rehabilitation treatment, such as occlusion, periodontal protection, pulp protection, and aesthetics [2]. In the case of dental crowns, whether temporary or permanent, a good marginal and internal adaptation is of great importance, as failure to seat the piece can result in low clinical longevity, marginal discoloration, caries, tooth sensitivity, plaque accumulation, and dissolution of cement [1].

There are several techniques for producing provisional using the conventional “analog” method, namely: alginate matrix, silicone matrix, stock teeth, pressed and plastic matrix [2]. It is important to highlight that these procedures are made up of followed manual steps that may present failures and depend on the manual skill of the operator for their success [3].

However, with the advent of digital dentistry in recent years, the availability of intraoral scanners has allowed the “virtual reading” of oral structures and the creation of prostheses through digital flow, using design software, 3D printers and /or milling machines. Popularly known by the acronym CAD\CAM (computer-aided design/computer-aided machine), the digital method is capable of consistently producing high-quality parts using different materials and equipment, with high patient acceptance [3,4].

Initially, the accuracy of margins in restorations produced via CAD\CAM faced significant criticism due to lower fidelity and lower-than-expected accuracy in the first systems available on the market from 1980 onwards, compared to traditional manufacturing methods. However, as these technologies have improved over time, this perception has been reversed. Currently, it is believed that the marginal integrity achieved by digital systems can be of excellent quality [5].

Therefore, the objective of this study is to digitally compare, through the method of image overlay and area calculation, the accuracy of provisional single-unit crowns produced by digital workflow using both subtractive and additive methods. At the end of this work, it is expected to discover which equipment (3D printer or milling machine) was able to better reproduce the characteristics determined in the virtual planning of the provisional crown.

The null hypothesis is that there were no differences in the crowns produced by the two production units used compared to the design projected in the design software.

MATERIAL AND METHODS

Dental preparation and reference crown fabrication

Initially, a full crown preparation was made on tooth 26 in a dental mannequin (Pronew, São Gonçalo, Rio de Janeiro), following the principles of wear in the silhouette technique. Subsequently, this preparation was scanned by a benchtop scanner (Identica Blue, Medit, Seoul, South Korea), and an STL file of the dental preparation was obtained.

The preparation file was imported into a 3D CAD dental software (dental CAD Valletta, Exocad, Darmstadt, Germany), and the design of a single-unit full crown was performed by a dental prosthetics technician with over 10 years of experience (Figures 1 and 2).

Production of crowns using milling machine and 3D printer

Using the file of the full crown, we began the fabrication phase of the provisional pieces using two different production units, a 5-axis milling machine (Programill dry, Ivoclar, Schaan, Liechtenstein) and a DLP 3D printer (Photon mono m5s, Anycubic, Shenzhen, China). Fifteen milled crowns (Figure 3) and fifteen printed crowns (Figure 4) were produced. The blocks

Figure 1 - Digital file of the preparation for total crown.

Figure 2 - Digital file of the total crown designed in dental modeling software (Dental CAD Valletta, Exocad, Darmstadt, Germany).

Figure 3 - Milled crowns.

selected for milling were PMMA (Evoblock multicolor, Evoden, Pirassununga, São Paulo),

Figure 4 - Printed crowns.

and the resin for printing was provisional type (Bio prov, Prizma, Birmingham, England).

Scanning of produced crowns

All produced pieces were scanned using an intraoral scanner (i700 Medit, Seoul, South Korea), thus generating 30 STL files, which formed 2 groups: group 1 - Milled and group 2 - Printed. The crowns underwent basic finishing to remove the supports used in production. The scans were performed by the same operator scanning each crown individually. For this step, the pink light filter was activated on the scanner, and the operator wore pink gloves. In this way, the pieces were held in hand, and their external part was scanned first, followed by the internal region

Image overlay and analysis method

The aim of the study is to evaluate the internal and marginal accuracy of these pieces, with the original design of the provisional crown projected as a reference. To assess internal accuracy, the internal area of all produced pieces (Figure 5) and the internal area of the reference (Figure 6) were calculated using 3D image analysis software (Medit Crown Fit., v 1.1.2, Medit Link, Medit, Seoul, South Korea). Using the same software, marginal accuracy was also evaluated using the image overlay method. In this method, each file of the produced crowns was individually aligned with the design of the projected crown, and sagittal cuts were made in the mesio-distal and vestibulo-lingual directions to measure the value of distortions found in the cervical region of interest (Figure 7).

Statistical analysis

For all statistical analyses, the Jamovi software was used, an open-source statistical

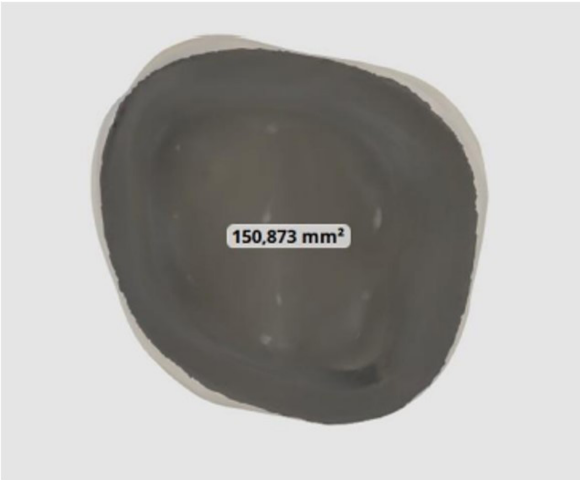

Figure 5 - Calculation of the internal area of milled crown 1.

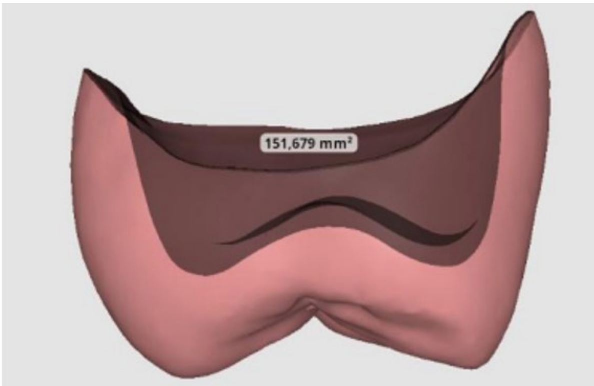

Figure 6 - Calculation of the internal area of the reference crown.

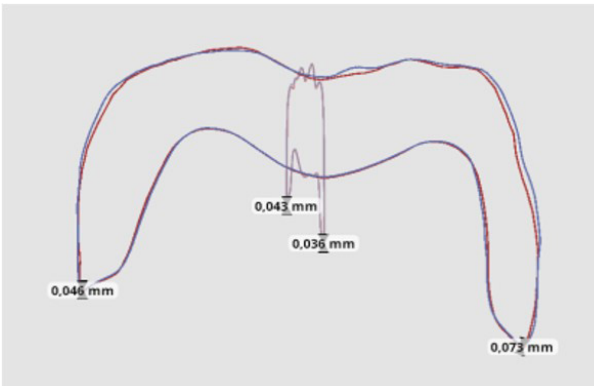

Figure 7 - Mesio-distal and vestibulo-palatal sagittal cuts for analysis of discrepancy in the cervical region of the fabricated piece. The red line represents the reference crown and the blue line the milled crown.

platform that offers a wide range of tools for data analysis (available at www.jamovi.org). Initially, the data underwent descriptive analysis. All values obtained from the internal areas were tabulated, as well as the values of distortions at the cervical margin of the pieces. The reference for calculating internal and cervical distortions was the original design projected in the 3D CAD dental software (dental CAD Valletta, Exocad, Darmstadt, Germany). To verify the normality of the sample data distribution, the Shapiro-Wilk test was used, with $p<0.05$ set as the threshold for significance. We proceeded with statistical comparison using Student's t-test for independent samples. This test was chosen for its suitability in analyzing differences within related groups when the data follows a normal distribution. We adopted $p<0.05$ as the criterion for determining the statistical significance of these comparisons.

RESULTS

During the process of calculating the discrepancies found between the manufactured total provisional single-unit crowns (group M - milled; group P - printed) compared to the original reference file designed in the Exocad® software, we obtained 30 measurements for internal area analysis and 120 measurements for marginal analysis of the pieces. Based on the data obtained through the Medit crown fit® 3D image analysis software, descriptive statistical analysis was performed for the two regions of interest (internal area and cervical area) of the crowns produced.

Based on the data obtained in Table I, it is observed that for the milled group, the face with the lowest average discrepancy (0.0353 mm) compared to the reference file was the Lingual, while the Vestibular face had the lowest standard deviation (0.0041), indicating less dispersed and more uniform measurements. For the printed crown group, the face with the lowest average discrepancy (0.143 mm) was the Mesial, and it also had the lowest dispersion among the measurements with a standard deviation of 0.0302. The total average of marginal discrepancies was 0.04843 millimeters for milled crowns and 0.2351 millimeters for printed crowns ($p<0.001$).

The data presented in Table II are related to the measurements of the internal areas of Group M and Group P. Group M (Milled) showed an average discrepancy of the internal area of 0.8111 mm² and a standard deviation of 0.6429, while group P (Printed) presented an average discrepancy for the internal area of 8.580 mm² and a standard deviation of

Table I - Descriptive analysis of the data obtained regarding the marginal discrepancies of the Milled (M) and Printed (P) crowns

	Group	N	Mean	Standard Deviation	Standard error	p-value
Buccal	M	15	0.0516	0.0171	0.00441	*p<0.001
	P	15	0.281	0.0424	0.01094	
Lingual	M	15	0.0353	0.0246	0.00636	*p<0.001
	P	15	0.307	0.0657	0.01698	
Mesial	M	15	0.0710	0.0185	0.00479	*p<0.001
	P	15	0.143	0.0302	0.00779	
Distal	M	15	0.0367	0.0191	0.00493	*p<0.001
	P	15	0.208	0.0516	0.01333	

*Student t-test with significant statistical differences.

Table II - Descriptive analysis of internal area discrepancies for Group M (Milled) and Group P (Printed)

	Group	N	Mean	Standard Deviation	Standard error	p-value
Difference in internal area	M	15	0.8111	0.6429	0.16598	*p<0.001
	P	15	8.590	0.9306	0.24027	

*Student t-test with significant statistical differences.

0.9306. Thus, regarding the internal area, there was a statistically significant difference when comparing groups P and M. Group P showed higher discrepancies compared to group M (p<0.001).

DISCUSSION

The comparative investigation of digitally manufactured provisional full crowns using milling machines and 3D printers has been the subject of extensive study in recent years, with various analysis methodologies being employed. Among these, the Silicone Replica technique stands out, followed by manual sagittal cuts and microscopic analysis [3]; Silicone Replica technique followed by microtomographic analysis [6]; and microtomographic scanning followed by digital image analysis [1]. A common point among these methods is the evaluation of internal and marginal adaptation of the pieces, through measurements of the internal spaces formed between the preparation walls and the interior of the crowns. The systematic review by Di Fiore et al. [7] describes these methodologies as also useful for analyzing the internal and marginal adaptation of partial crowns.

In the present study, an adapted methodology was implemented for comparing printed and milled provisional crowns. A double scanning technique was utilized, where scanning of the dental preparation and the produced piece separately allowed alignment of the reference 3D file with the obtained manufacturers. The results enabled the assessment of the accuracy of these crowns in relation to the design projected in the design software. After statistical analysis focused on marginal precision, it was observed that Group M (Milled) exhibited a lower mean discrepancy (0.04843 mm) compared to Group P (Printed) (0.2351 mm), along with lower standard deviation values, indicating greater fidelity to the reference file and more uniform measurements.

These findings corroborate the study by Wu et al. [6], which found better performance in the marginal adaptation of milled provisional crowns compared to printed ones. However, they diverge from the results of Alharbi et al. [1], which indicated better marginal adaptation of printed crowns compared to milled ones. In Viega's study [8], which compared the reproduction trueness and precision of dental casts made by the conventional, milling, and 3D printing techniques, it was shown that the milling technique was found to be significantly more accurate than the conventional and 3D printing techniques, which corroborate our findings.

Regarding the statistical analysis of the internal area, it was observed that Group M exhibited a lower mean discrepancy (0.811mm^2) and standard deviation (0.643) compared to

Group P (8.59 mm^2) and (0.931), indicating higher accuracy. These results contradict the findings of Alharbi et al. [1], who demonstrated better performance in internal adaptation for printed pieces. These discrepancies may be attributed to differences in brands and models of equipment used and in the research methodologies adopted.

In general, this study has shown that milled crowns exhibited greater accuracy compared to the original design projected in the 3D CAD software (Exocad®) than printed crowns, both in the internal and marginal areas. One possible explanation for the lower performance of 3D printers in this study could be based on the studies by Della Bona et al. [9], whose systematic review concluded that the printing angle used can impact the accuracy of the print, as well as properties such as strength, morphology, and biocompatibility.

The null hypothesis of this study was rejected, indicating deviations in both production methods. However, several studies have already demonstrated that both 3D printers and milling machines have the ability to produce restorations with adaptation within the recommended parameters [10]. These promising technologies have contributed to greater predictability and quality in dental work [11].

The clinical relevance of this study lies in the analysis methodology employed, which, if applied in daily clinical practice, allows for the anticipation of problems and the evaluation of distortions and misfits in the produced prosthesis before their installation, thus contributing to a reduction in clinical adjustment time and greater effectiveness in results.

CONCLUSION

Provisional single-unit total crowns obtained by milling demonstrated superior accuracy and precision when compared to their counterparts produced by 3D printing, both in the internal and marginal areas. Further studies are recommended, employing updated methodologies, in the field of manufacturing provisional crowns for fixed prostheses using the CAD/CAM system.

Author's Contributions

ABV: Writing – Review & Editing. DHN: Conceptualization, Methodology. IIK: Software, Validation, Writing – Original Draft Preparation. EK: Visualization, Investigation, Supervision.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Regulatory Statement

This study was conducted in accordance with the guidelines and ethical standards of the Institution. There was no involvement of human subjects, nor any collection of personal data. The authors declare that there are no conflicts of interest related to this research.

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