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Patient Satisfaction with Anterior Interim CAD-CAM Rehabilitations Designed by CAD Technician versus Trained Dentist—A Clinical Preliminary Study

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Abstract: The objective of this study was to assess the impact of digital waxing expertise on patient satisfaction with anterior interim computer-aided design and computer-aided manufacturing (CAD-CAM) prosthetic rehabilitations designed either by a CAD and dental technician or by a dental clinician with basic CAD-CAM training. This in vivo preliminary study was conducted on a total of 18 patients receiving anterior CAD-CAM rehabilitations (at least from canine to canine) with fixed bridges and/or single crowns. Only patients that had conventional chairside temporary restorations were enrolled. Three within-patient groups were defined at different time points: group CONTROL refers to all 18 patients at their first appointment, when they were using their initial temporary conventional prostheses; group DENT refers to all patients immediately after trying in a set of CAD-CAM prostheses designed by a dental clinician (with basic one-week CAD-CAM training); and group CAD refers to all patients after trying in a set of CAD-CAM prostheses for the same tooth elements but designed by an experienced CAD technician (who was also an experienced dental prosthetic technician). All CAD-CAM restorations were milled in polymethyl methacrylate (PMMA) with high translucency and strength properties (Prime, Zirkonzahn). Satisfaction with comfort and esthetics was assessed for all patients for the three different time points (groups CONTROL, DENT and CAD). Statistically significant differences among groups were assessed with the Friedmann's test. Group CAD significantly outperformed the other groups in both assessed variables ($p = 0.001$). The group DENT, in turn, outperformed group CONTROL for satisfaction with esthetics ($p = 0.006$) but not for comfort ($p > 0.05$). In conclusion, CAD operator background and expertise level significantly affect patient self-reported outcomes for anterior CAD-CAM rehabilitations. Single crowns and fixed bridges digitally designed by an experienced professional trained in both CAD-CAM and dental technology will likely offer high satisfaction and comfort to patients receiving anterior prosthetic rehabilitations.

Keywords: computer-aided design; 3D printing; interim single crown; patient satisfaction; self-assessment; questionnaire study; prosthetic rehabilitation; anterior esthetic restoration

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1. Introduction

Computer-aided design and computer-aided manufacturing (CAD-CAM) have been gaining popularity in restorative dentistry [1]. Among the main reasons are the ongoing technological development of CAD software programs, 3D printing and milling procedures. In this context, the process of producing CAD-CAM restorations is sensitive to every step of the methodology, regardless of the material to be used in the manufacturing process. Interim CAD-CAM restorations can be designed on intraoral scans (IOS) of tooth preparations imported into CAD software and produced with milled PMMA with satisfactory accuracy to manage surrounding soft tissues and predict esthetic and functional outcomes

of permanent crowns [2,3]. Interim crowns can also be produced with light-cured resin by means of 3D printing. This, in turn, is an additive manufacturing method to manufacture solid objects layer-by-layer from a 3D digital design file, usually offered in the "Standard Tessellation Language" (STL) extension [4,5]. This digital workflow is achieved with enhanced communication between patients and professionals, as well as among different professionals (i.e., dentists, dental technologists, etc.) [2]. As a result, metal-free esthetic restorations have obtained an increasing space in the market. The number of biomaterials used in dental CAD-CAM has also increased, along with blocks and discs (blanks) of feldspar ceramics, titanium, zirconia, lithium disilicate, cobalt chromium and resin for temporary prostheses, depending on the purpose of the treatment. It is suggested that all the steps of a digital workflow (i.e., intraoral scan, CAD and CAM) may influence the fitting precision of indirect permanent restorations [1,2].

Dental commercial CAD software programs usually have similar tools and workflow interfaces. First, the professional should start by inputting the patient's data, as well as details of the project to be performed. This is carried out along with the identification of the dentist, technician and type of work performed, which are stored in the patient's file and used with the next software program of the workflow, which will be used to digitally design the restorations registered in the project. Such software interface also enables the possibility of importing and using the patient's photographs, which in turn can be integrated and superimposed with intraoral scans of the patient, and even cone-beam-computed tomographic scans, if surgical procedures involving bone tissue are also part of the project [1,2,6].

One very important difference between software programs, however, is the number and types of tooth libraries available. It is important to choose a tooth library compatible with the patient's face and dental arch [7–9]. For this reason, a satisfactory protocol of clinical photographs should always be used in the initial appointments of the patient. To address this difference and decrease the level of bias, previous research studies have used mirroring techniques to compare CAD software programs, instead of using standardized libraries [3,9].

There are two main types of digital workflow in restorative dentistry: laboratory and chairside workflows. In this context, chairside CAD-CAM systems usually have intraoral scanners integrated with milling devices of the same brand. On the other hand, open CAD software programs have also developed chairside versions, with interfaces that are user-friendly for dental clinicians [1]. It is unclear, however, what is the impact of the choice of CAD-CAM system and related materials on the final CAD-CAM restoration.

Recent previous studies have found that CAD-CAM outperforms conventional prostheses regarding clinical outcomes [3]. On the other hand, CAD-CAM requires digitally waxing tooth morphology by copying/mirroring a contralateral tooth or using CAD software libraries, followed by personalized adjustments [1]. These, in turn, are time-consuming and may influence the adaptation [7], as well as functional and esthetic features of the final restoration [1]. The main question of this study was whether the CAD-CAM expertise and experience of the operator designing the crowns significantly affect patient satisfaction and self-reported outcomes of CAD-CAM dental prostheses. An additional question was whether the software and operator experience significantly affect the time required to digitally design anterior maxillary CAD-CAM rehabilitations.

Thus, the aim of this study was to assess the impact of operators with different levels of expertise and training (i.e., a professional trained in both dental and CAD-CAM technology, and a dental clinician with basic one-week CAD-CAM training) on satisfaction and self-reported outcomes of patients receiving anterior CAD-CAM prosthetic rehabilitations, as well as on the time taken to digitally design the entire set of anterior maxillary CAD-CAM prostheses.

2. Methods

This clinical preliminary study was conducted in 18 patients who were consecutively referred for anterior maxillary prosthetic rehabilitations, and who already had satisfactory tooth preparations for resin crowns loaded with conventional chairside acrylic resin temporary restorations (Group CONTROL). The protocol of this study was approved by the ethical committee of the University of Malta (Protocol number DSG/2020-2021/05). Each patient had at least five subgingival preparations to rehabilitate at least all anterior maxillary teeth (i.e., from canine to canine) with either single crowns or fixed bridges. All patients had natural antagonist anterior mandibular teeth arch at time of the study. The same digital workflow was used to treat all patients of this study (Figure 1).

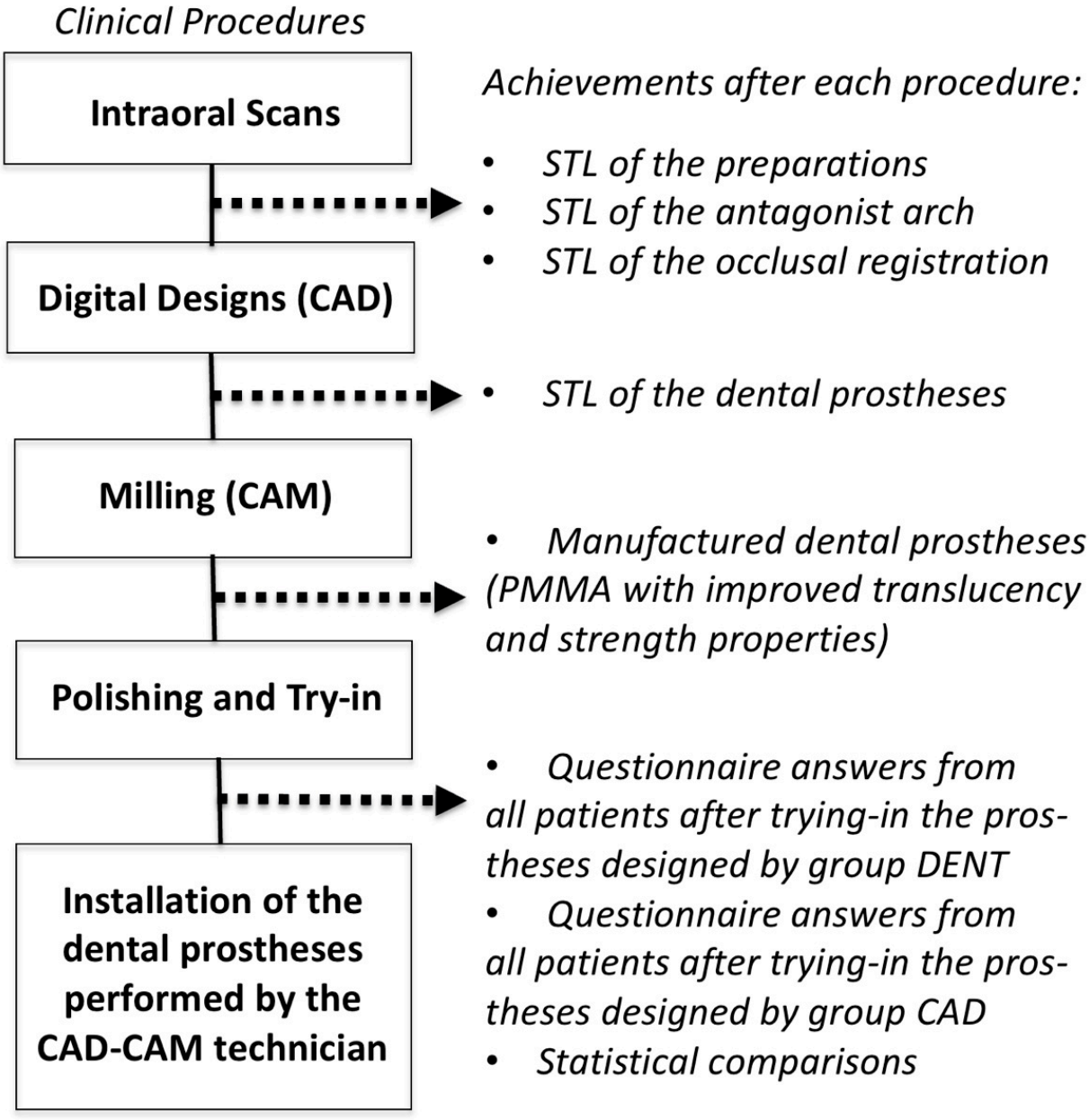

Figure 1. Flowchart of the digital workflow used in this study.

At the beginning of the first appointment, each patient was given a questionnaire with two Likert scale questions [6], using a 10-point scale to assess their level of satisfaction with their current conventional temporary dental prostheses, following a previously described

methodology [7]. The first question aimed at obtaining a score for the satisfaction with esthetics, whereas the second question assessed the comfort of the patient when biting.

All anterior preparations were then scanned using the same intraoral scanner (TRIOS 4, 3Shape A/S, Copenhagen, Denmark). This scanner uses confocal technology with an accuracy of less than 20 microns for X and Y axes. Intraoral scans of the antagonist arch and of the occlusal registration were also obtained with the same scanner. All aforementioned intraoral scans were saved as "Standard Tessellation Language" (STL) files, after being checked and cropped properly.

All sets of STL files from IOS of each case were given to a CAD-CAM and dental prosthetic technician with more than 5 years of experience in digital waxing (group CAD) and to a dental clinician with basic one-week training and less than six months of experience to digitally design single crowns and/or fixed bridges (group DENT). The dentist had more than 15 years of experience in oral rehabilitation. All STL files were imported to one of two dental CAD software programs (either DentalCAD 3.0 Galway, Exocad GmbH, Darmstadt, Germany; or Modellier, Zirkonzahn, Gais, Italy) to digitally design all anterior maxillary restorations (either single crowns or fixed bridges) required to rehabilitate the anterior maxilla. All digital designs were performed with free choices of libraries or by copying/mirroring existing anatomy. However, the CAD-CAM technician also performed a digital mock-up to be presented to the patient before performing any CAD-CAM crowns, in order for the patient to make the decision of accepting the proposed oral rehabilitation treatment plan. All designed restorations were manufactured from a polymethyl methacrylate (PMMA) material with improved translucency and strength properties (Prime, Zirkonzahn, Gais, Italy) using the same 5-axis milling device (M1, Zirkonzahn, Gais, Italy), with the "quality" protocol and all corresponding drills, as recommended by the CAM software of the manufacturer (Nesting, Zirkonzahn, Gais, Italy). The only post-manufacturing procedures performed were the removal of the PMMA disk attachments and polishing with a silicone polishing kit for PMMA (JOTA, Ruthi, Switzerland).

All patients initially assigned to group CONTROL tried in two different sets of CAD-CAM prostheses (i.e., the rehabilitation designed by the group CAD and by the group DENT) consecutively in random order (Figure 2) and stayed with each set for 5 min. For this purpose, all teeth preparations were dried, and the occlusion of the patient was checked using an articulating paper (horseshoe/full arch, red/blue articulating film; Ardent, Inc., Ossining, NY, USA). All clinical and try-in procedures were performed by a dental clinician with more than 5 years of experience. After using each set of dental prostheses for 5 min, each patient was given a new questionnaire with the same two Likert scale questions [6] that were answered in the first appointment, but now to assess their level of satisfaction with each new set of CAD-CAM dental prostheses (groups DENT and CAD) [7]. Then, the set with the best outcomes was cemented with temporary cement (Tempbond NE, Kerr, Orange, CA, USA) as long-term temporary crowns to rehabilitate the patient. Patients were also asked to answer a questionnaire with 2 open-ended questions about the acceptability of the treatment, and about their experiences with both conventional and the current digital workflow used in their treatments.

The sample size calculation for the pilot studies was conducted with the Noether's formula, considering a desired statistical power of 80% and a level of significance of 5%. Since both parameters of satisfaction analyzed were categorical variables assessed with a Likert scale, non-parametric statistical differences among groups were assessed with the Friedmann test with post hoc Wilcoxon Signed-Rank tests to address pairwise differences. Finally, an additional comparison of the time taken to perform digital waxing by both groups (in minutes) and both software programs was conducted with the Student T-test. All analyses considered a significance level of 5% and were performed with the SPSS Statistics 28 software (SPSS, Inc., Chicago, IL, USA).

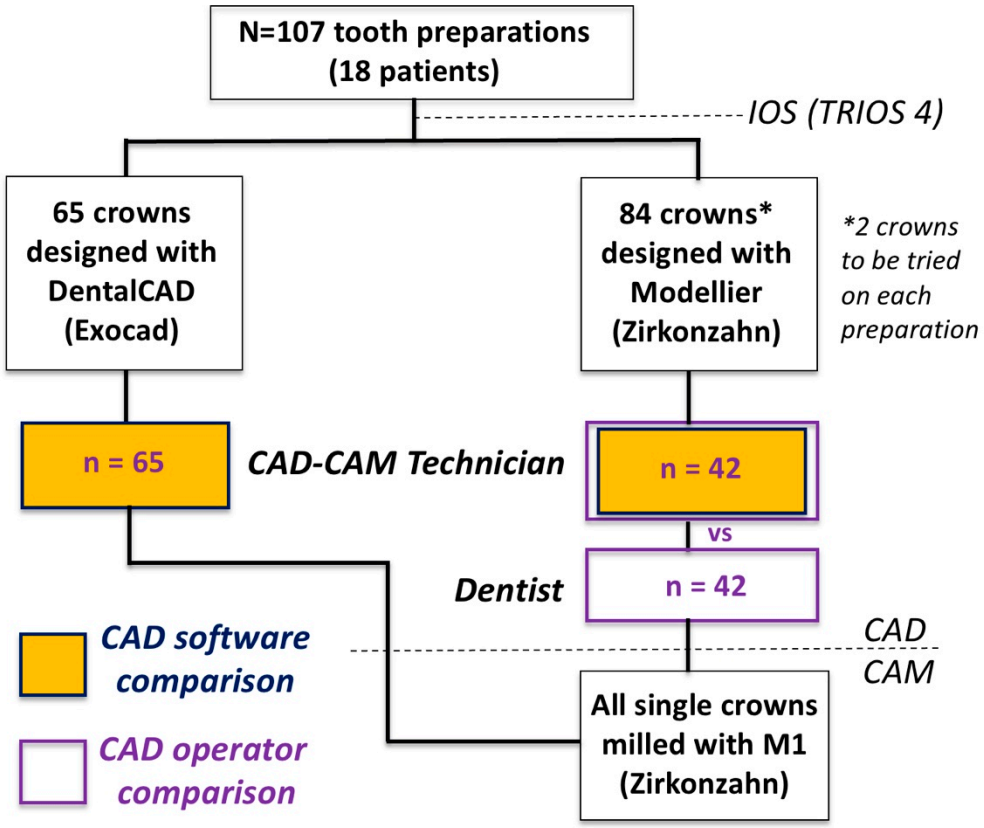

Figure 2. Flowchart of the study design.

3. Results

A total of 108 single-tooth prostheses were successfully designed and milled with the five-axis milling device (M1, Zirkonzahn) for the 18 patients included in the study. All 18 anterior CAD-CAM rehabilitations could be successfully tried intraorally in both test groups (CAD and DENT), which used two software programs that have similar interfaces (i.e., DentalCAD and Zirkonzahn Modellier). For this reason, no distinction or comparison between software programs was conducted herein. However, half of the CAD-CAM rehabilitations of the group DENT (n = 9) had at least one prosthesis requiring chairside adjustments of interproximal contacts to obtain adequate seating. In addition, 10 of the 18 rehabilitations of this group required occlusal adjustments due to excessive antagonist contacts. On the other hand, no chairside adjustments were required to obtain adequate seating of the restorations of the group CAD (Figure 3).

The median and range of the Likert scale results for the three groups are available in Table 1. Group CAD significantly outperformed the other groups in both assessed variables ($p = 0.001$). The group DENT, in turn, significantly outperformed group CONTROL for satisfaction with esthetics ($p = 0.006$) but not for comfort ($p > 0.05$). In addition, the mean time required to perform digital waxing was 6.2 ± 2.9 min for the CAD group and 10.2 ± 3.1 min for the DENT group ($p = 0.001$ according to the Student *t*-test). On the other hand, there were no significant differences between time required using different software programs ($p = 0.522$).

Qualitative analysis of the virtual wax patterns revealed that interproximal contours at the cervical third were the most challenging tooth anatomical landmarks to be satisfactorily designed and reproduced by the DENT group, as these were the main areas with decreased clinical esthetic outcomes, as compared to the CAD group. The second-most-challenging aspect of virtual waxing for the DENT group was the design of interproximal and antagonist contacts, which led to the necessity of performing chairside adjustments in several of the CAD-CAM crowns of this group, as explained above.

Table 1. Median and range of results and statistical differences between CAD operators designing anterior CAD-CAM rehabilitations.

Likert Scale Questions	Group CONTROL	Group CAD	Group DENT	*p* Value *
Satisfaction with esthetics	6 (4–8)	10 (8–10)	8 (7–10)	0.001
Satisfaction with comfort	8 (5–10)	10 (9–10)	8 (6–9)	0.001

* Friedmann's test. Bold font means statistically significant differences.

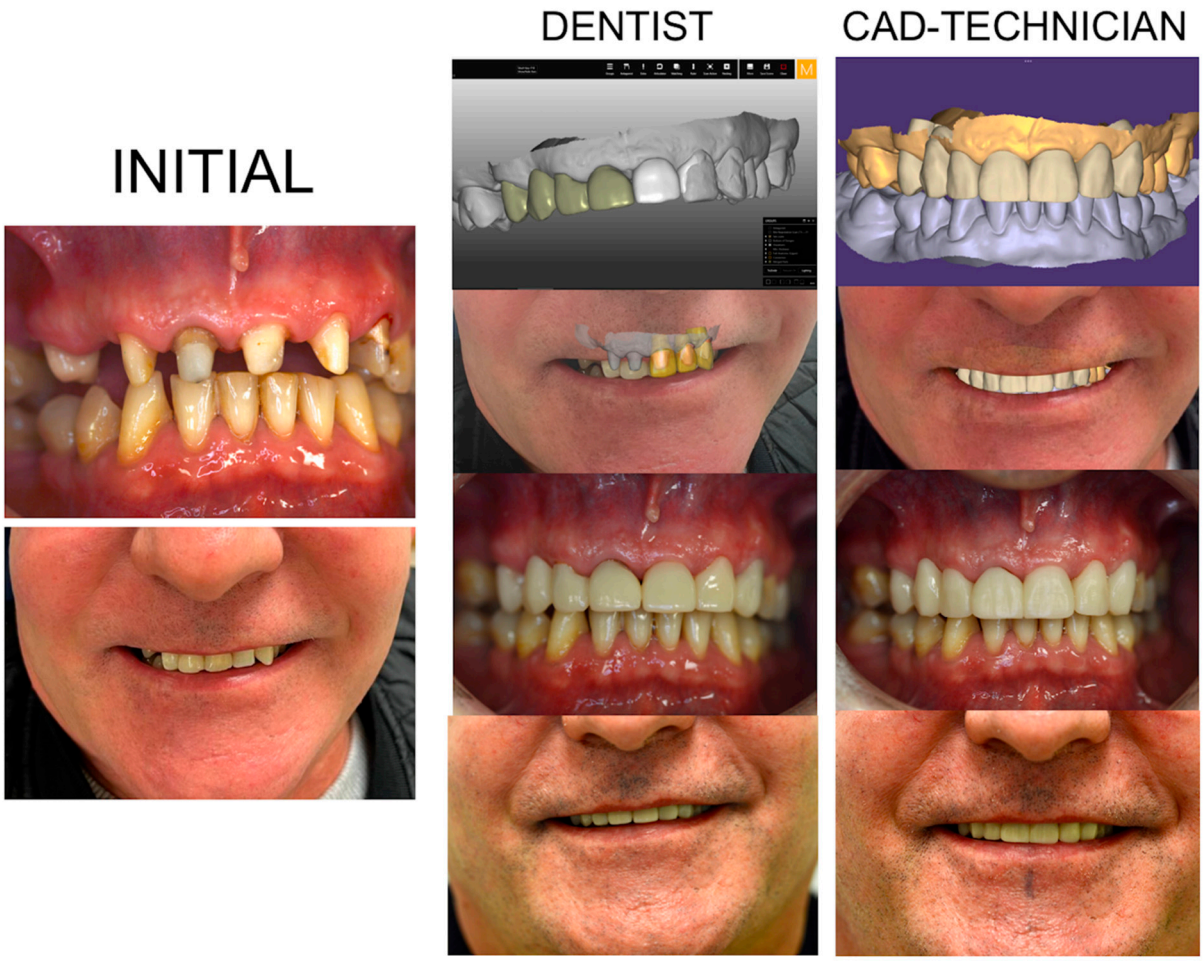

Figure 3. Example of a case included in the comparison between groups CONTROL (initial situation with conventional temporary crowns), DENT (try-in of CAD-CAM prostheses designed by a dentist) and CAD (try-in of CAD-CAM prostheses designed by an experienced CAD-technician). Questionnaire results from all patients were obtained in the three treatment phases depicted above.

Open-ended questions were qualitatively analyzed. The following trends were identified by the results: All 18 patients had previous experiences with conventional workflows involving impression materials, and all stated their preference to be treated with digital workflow involving digital impressions with intraoral scanners. All patients also stated that they were confident during the follow-up period of this study to bite with the anterior crowns installed. In addition, a total of 15 patients (83.3%) described that seeing the digital mock-up before even starting their CAD-CAM crowns (i.e., while the patients had their conventional temporary crowns) was important to make the decision to accept the proposed oral rehabilitation treatment plan (Figure 4).

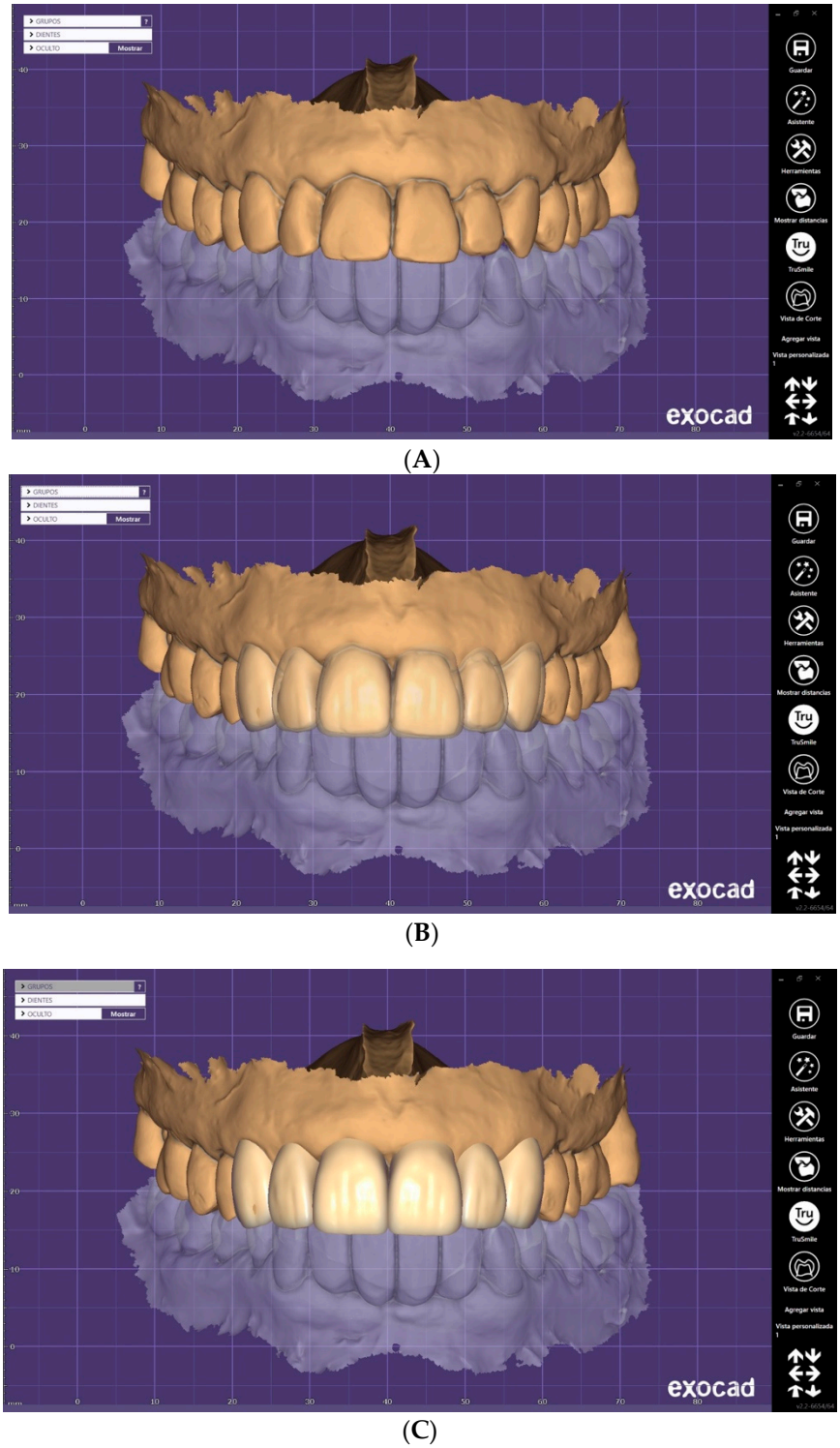

Figure 4. (**A**) Initial intraoral scans of a patient using an unsatisfactory set of conventional temporary crowns, imported to the CAD software (DentalCAD). (**B**) Intraoral scans with the superimposition of the digital mock-up of the same case. (**C**) Final result of the digital mock-up of the same case.

Due to the superior outcomes of the CAD group, all crowns installed on patients after the analyses belonged to this group. None of the cases presented any post-treatment complications for the long-term PMMA crowns produced in this study. The colors chosen of the modified PMMA blanks were satisfactory for all crowns, even after temporary cementation, which confirms the satisfactory role of the material in maintaining good

esthetic conditions as long-term temporary restorations. The mean patient follow-up periods were similar for both groups at 6.2 ± 4.7 months.

4. Discussion

This preliminary in vivo study aimed to compare patient satisfaction and clinical outcomes of anterior rehabilitations with multiple CAD-CAM milled single crowns designed by professionals with different backgrounds and levels of expertise. According to the present findings, CAD-CAM anterior interim rehabilitations had increased patient satisfaction, compared to the initial conventional temporary rehabilitation, which is supported by previous studies [1]. Furthermore, the superior results found herein by the group CAD over group DENT support the importance of the learning curve in dental digital workflow [2]. In this context, digital waxing performed after integration and alignment of IOS and patient pictures or facial scans require software knowledge and practice [3].

This study supports the importance of CAD and software knowledge to perform virtual waxing at the esthetic region [10]. Interestingly, an opposite finding was seen by a previous study on virtual waxing of posterior single crowns, in which clinical experience was considered more important than CAD experience and software knowledge to obtain the best outcomes [8]. However, the present study also described that even the time to perform virtual waxing was significantly higher for the DENT group. This is also in accordance with the fact that operators of the present study had an additional IOS of the main arch with the conventional temporary crowns, to copy existing anatomy whenever deemed adequate, which was probably better used by the CAD group. This finding is also in agreement with two previous studies that found less occlusal interferences and better outcomes with higher patient satisfaction by copying a pre-existing anatomy during digital waxing, compared to using CAD libraries only [11,12]. Nevertheless, studies from even previous years presented opposite findings, with significantly better outcomes using a CAD library [13], or even similar results between digital wax patterns generated by a fully automated CAD software program and conventional wax patterns performed by experienced dental technicians [14].

This is the first study suggesting the impact of CAD operator expertise on large anterior CAD-CAM rehabilitations. It is noteworthy that although all crowns manufactured herein were tried in, only the crowns designed by a CAD-CAM technologist were ultimately installed and followed up. The favorable questionnaire outcomes obtained by the crowns designed by the dentist are in agreement with several studies in the literature describing the usefulness and predictability of chairside steps of digital workflows [15–25], including for rehabilitations involving dental implant therapy [26–33]. This is a clinically relevant finding, since the dentist usually plays a major role in the design and manufacture of the CAD-CAM restorations when a chairside digital workflow is performed. However, the present findings contrast with a previous CAD study on single crowns, in which CAD expertise did not affect digital waxing accuracy [8,9]. On the other hand, our results are in agreement with another CAD study suggesting that CAD expertise affects outcomes of digital wax patterns of anterior CAD-CAM laminate veneers [10].

Two different software programs were used in this study (DentalCAD, Exocad GmbH; and Modellier, Zirkonzahn). However, both software programs have a similar interface designed to be used by CAD-CAM laboratories and technicians. This justified the lack of significant differences between crowns performed with these two CAD software programs, as previously suggested by the literature [10]. The aforementioned citation, however, states that there are significant differences in comparisons between dental commercial CAD-CAM software programs and free open-source CAD-CAM software programs which are not specifically dedicated to the dental field. These findings elucidate why CAD-CAM expertise and experience is one of the most critical factors in the success of CAD-CAM rehabilitations, as previously described [9,10]. This is particularly relevant for the two well-known state-of-the-art laboratory CAD software programs used herein. Despite the relatively similar interfaces, one of the present software programs was created for open systems (DentalCAD,

Exocad), and the other (Modellier, Zirkonzahn) is directly integrated to a milling device that is part of an established CAD-CAM system (Zirkonzahn), commonly used in dental laboratories and dental clinics with in-house CAD-CAM laboratory production and has presented high accuracy in previous research [34]. It is also important to mention that the Modellier software can also export the digital designs of dental prostheses as STL files, which enables comparisons and digital assessments used in CAD-CAM dental research [8–11].

This study used an integrated laboratory CAD-CAM system with a high-end five-axis milling device (Zirkonzahn M1). Laboratory milling is a more complex procedure but has shown superior results compared to chairside milling devices [35]. Nevertheless, the milling machine of the system used herein was found in to be user-friendly for the dentist of this study and has physical structures that withstand any vibrations during the milling process, which leads to increased accuracy and precision as advantages of this system, which uses a proven technology of simultaneous use of 5 + 1 milling axes. This procedure is controlled by a computer and includes eight exchangers of drills and milling burs, as well as three block changers. Another advantage of the system is the possibility of virtually positioning the prostheses and objects to be milled inside the block using an interface of user-friendly software (Zirkonzahn Nesting). This procedure can actually be performed manually or automatically, and then corrected or amended manually if needed. On the other hand, although the software and devices of this system are integrated, there is a tool to enable importing STL files of prostheses designed on other software programs to be milled at the milling machine of the system, as performed herein with the Zirkonzahn M1. The system has also fully automatic and high-resolution optical light scanners, which are also automatically integrated to the CAD software programs and CAM systems.

Several methods have been used to measure accuracy and precision of CAD-CAM restorations. Among the main methods are 3D mesh superimposition and digital caliper linear measurement [3,4]. However, a digital caliper should only be used with a precision of two decimal places and with the caliper tips positioned on marks designed on the crowns on each pair of opposing vertical surfaces. Even these measurements are only valid if performed at least twice by two or more trained observers at intervals of two weeks to eliminate bias from memorized procedures. Three-dimensional mesh superimposition, in turn, requires an extra digitalization procedure of the manufactured crowns, which can be performed with intraoral scanners that have 360 scanning tools. Then, the STL files of the scanned crowns can be digitally aligned with their respective digital wax patterns CAD software programs dedicated for 3D mesh comparisons. Other studies have assessed accuracy of CAD-CAM systems by means of measuring marginal and internal gaps of the dental prostheses on their respective abutments. It is noteworthy that this preliminary study assessed patient-centered variables, which shows the role of CAD-CAM and the technological development in dentistry as an advantage that comes for the benefit of the patient [2]. Therefore, the aforementioned citation is supported by the present findings, since its authors described how digital dentistry plays an important role in decreasing the chairside time and number of appointments, while at the same time increasing communication between professionals, reproducibility of clinical results and predictability of oral rehabilitations, in accordance with their virtual treatment plan.

Among the main limitations of this preliminary study are the small sample size and the cross-sectional design. Furthermore, only patient self-reported outcomes of satisfaction were assessed herein. Another important limitation is that only one CAD-CAM technician and one dentist designed all the prostheses. To mitigate this issue, a very experienced CAD-CAM technician who was also a certified dental technician was selected. It is important to note that, although two operators are enough to confirm reproducibility of a method, more professionals with different backgrounds using the same software would be needed to address the sole impact of the level of expertise on the final clinical outcomes of CAD-CAM rehabilitations. Moreover, only laboratory CAD software programs were used herein, whereas chairside CAD software programs could lead to different results for the dentist. Therefore, future long-term prospective randomized clinical trials with larger sample sizes

would be recommended to address the impact of professional CAD-CAM knowledge and expertise levels on clinical results of interim CAD-CAM resin crowns. In addition, future studies are also recommended to test other important characteristics such as flexural strength [36], fatigue [37], roughness [38] and color stability [39], in order to investigate mechanical behavior of resin-based materials.

5. Conclusions

Within the limitations described above, the present preliminary findings suggest that CAD-CAM operator background and expertise levels significantly affect a patient's self-reported outcomes such as satisfaction with anterior maxillary interim CAD-CAM rehabilitations. The present findings also suggest that CAD-CAM training significantly affects the time required to digitally design anterior maxillary CAD-CAM prostheses. Future prospective clinical long-term studies would be recommended to confirm the present results with different operator training methods, software programs and CAD-CAM systems.

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Conflicts of Interest: The authors declare no conflict of interest.

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