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DOTTORATO DI RICERCA IN
MEDICINA MOLECOLARE – ODONTOIATRIA DIGITALE

CICLO XXXVII

*From traditional to digital workflow in dental
practice: comparison of clinical methods and
definition of modern CAD-CAM protocols*

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Introduction

Digital dentistry is an umbrella term for any dental practice involving digital technologies and computer-based systems. The establishment of the digital universe has involved and revolutionized every field of the dental profession, from diagnosis to treatment planning, from surgical practice to prosthetic technique, and on to patient care and undergraduate and postgraduate teaching. The application of digital systems to the practice of dentists was conceived in the late 1970s by Francois Duret when he processed the first digital image of a tooth using CAD/CAM principles to take the first optical impression [1]. After almost 50 years, many digital and computer-guided machines have begun to be introduced into the daily practice of dental offices worldwide, such as intraoral scanners, digital radiology, computer-aided design software, computer-aided milling machines, facial scanners, and 3D printers. This phenomenon inevitably results in replacing materials and protocols that have characterized traditional dental practice for many years, mainly related to the experience and expertise of the practitioner. The advantages of modern digital protocols in dental offices include high accuracy, shorter operating times, greater comfort, and easier and more effective communication with the patient. In addition, computerized surgery planning provides the ability to pre-visualize the outcome, build custom surgical guides, and make some

types of treatment less operator-dependent. Finally, digitalization offers the ability to store large amounts of data, photos, and dental models of the patient without wasting space and material and to correspond artifacts and impressions with the dental laboratory without couriers, resulting in an eco-friendly way of daily work. However, the computerized practice also possesses potential limitations. The first limitation is related to the dentist's initial approach to digital tools: the high cost of the equipment and the learning curve required to use it effectively make the initial investment unattractive for professionals accustomed to traditional practice.

Moreover, data security and privacy concerns must be addressed to protect patient information in digital systems. Another limitation is the reliance on technology, as technical malfunctions or system failures could disrupt dental workflows and potentially compromise patient care [2]. Finally, not all dental practices can be carried out through digital technology, thus requiring practitioners to possess traditional materials to deal with certain types of therapy when needed. Regardless of limitations and advantages, it is now well established that digital devices have rapidly spread to dental practices worldwide. The most popular tools in daily workflow are intraoral scanners, digital radiographs, CAD-CAM systems, and 3D printers.

Intraoral scanners (IOS) are digital cameras that capture direct optical impressions in dentistry. Regardless of the imaging technology employed by an IOS, all cameras require the projection of light that is recorded as individual images or video and compiled by the software after recognizing the points of interest (POI). The multiple

sets of points (or point clouds) generated through the optical sensors are subsequently registered (aligned with respect to each other) and are converted into a surface model represented as a triangle mesh. Therefore, a mesh in a 3D scan refers to how the surfaces are represented in the software via computer graphics. A mesh is a collection of vertices and triangles and includes information on how the vertices make up the triangles and how the triangles are connected to each other [3]. The result is a 3D model of the dental arches, soft tissues, and any devices that may be present in the oral cavity (e.g., implant scanbodies).

IOSs, compared with traditional impression materials, possess several advantages, including greater ease of use, greater speed, better patient comfort, the ability to communicate with the dental technician and the patient himself more efficiently and quickly, and no longer needing physical space to store plaster models. On the other hand, IOSs require a more significant learning curve and higher initial and maintenance costs than traditional impressions [4]. In addition, one of the most reported problems in the literature regarding IOS concerns the difficulty in detecting deep marginal lines on prepared teeth or in case of bleeding [5]. In some cases, and especially in aesthetic areas where the clinician needs to place the prosthetic margins subgingivally, it may be more difficult for the light to detect the entire finishing line correctly. In fact, unlike the conventional impression materials, light cannot physically detach the gum and, therefore, cannot register 'non-visible' areas. Similar problems can also occur in the event of bleeding, as blood may obscure the prosthetic margins

[6, 7]. Chapters 2 and 3 present a full-digital method of creating the emergence profile of a crown using a subgingival dental preparation technique (Verticalized Edgeless Preparation). These innovative workflows adapt traditional procedures and concepts onto a more modern methodology relying on computer technologies, proposing a solution to transfer the accuracy of reading prosthetic margins typical of the conventional impression to the convenience of using IOS in a fully digital context. By following some recommendations and with the help of clinical tricks, a final digital impression of a natural prosthetic abutment with subgingival preparation can be obtained, circumventing the problems associated with gingival bleeding and the difficulty of the light in detecting the non-visible areas below the gingival sulcus. This also allows the prosthetic margin to be placed subgingivally through software design in a way that does not interfere with proper soft tissue healing.

Accuracy and trueness between scanned data and reference data have been comprehensively studied. Results, even with scanners that are earlier designs, show small differences between intraoral scanned data, extraoral scan data, and data from conventional impressions/models though all are within acceptable limits for clinical use. The major concern, however, is whether the appliance produced based on intraoral scan data are equal to those produced from conventional impressions [8].

Chapter 1 examines the accuracy, specifically mandibular advancement devices (MADs), produced both from traditional and digital impressions. To date, no study in the literature has evaluated the use of optical impressions in the manufacture of

MADs and, overall, no study has investigated aspects such as the accuracy, fit and comfort of MADs in relation to the device manufacturing process. The study was accompanied by a systematic review investigating the relationship between periodontal disease in adults and obstructive sleep apnea syndrome, a fairly common condition that can have serious consequences for daily life and for which MADs are a primary therapeutic option in some cases.

Today, virtually any intraoral device can be produced from a digital impression through a digital design (CAD) and manufacturing (CAM) operation. Computer-aided manufacturing processes can be divided into subtractive manufacturing, which refers to the milling of blocks of material such as ceramic, wax or resin with precision milling cutters, and additive manufacturing, which refers more specifically to 3D printers.

Three-dimensional (3D) printing technologies are advanced manufacturing technologies based on computer-aided design digital models to create personalized 3D objects automatically [9]. They have been widely used in the industry, design, engineering, and manufacturing fields for nearly 30 years. In the field of dentistry, additive manufacturing technology has revolutionized the way of working, enabling the production of intraoral devices including everything from simple models, wax forms, tooth-colored temporaries and surgical guides to more complex long-term metal and ceramic prostheses and digitally manufactured full dentures. Although seven different 3D printer technologies are available, four are most commonly used in dentistry: stereolithography, digital light processing, material jetting and material

extrusion. Depending on the system, material choices include glass ceramics, cobalt chromium, composites, PMMA, Resin/polymers, wax, titanium, zirconia, with ever more choices becoming available with new material innovation [10]. Benefits of 3D printing applications in dentistry includes lower cost for the patients, a more personalized service and the simplification of the workflow related to the production of dental appliances, which results in less time for implementation [11]. In prosthodontics in particular, the main uses of 3D printing are the production of provisional crowns or bridges, complete dentures or removable partial dentures frameworks. Temporary crowns fabricated using 3D printing were found to have excellent edges and internal fit, which are more accurate than temporary crowns fabricated applying CAD/computer-aided manufacturing (CAM) or traditional milling methods [12]. Digital additive manufacturing can also be combined with conventional manufacturing in the production of definitive fixed partial dentures, using 3D printed polymer artefacts to replace wax models in the ceramic pressing process [13].

Chapter 4 examines the difference in accuracy between restorations made by conventional methods and those made from 3D printed artefacts. Specifically, fitting and marginal accuracy of lithium disilicate overlays fabricated by a 'classic' method, using traditional impressions and pressing of ceramics from a hand-made wax artefact, and a computerized method, using digital impressions and pressing of ceramics from a 3D-printed polymer artefact, will be measured using micro-CT examination. The study also examines the accuracy of digital dental models produced

by different types of 3D printers and their use in the production of indirect restorations using conventional workflow.

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Chapter I

Double-blind comparison between optical and conventional impressions for the production of mandibular advancement devices

1.1 INTRODUCTION

Obstructive sleep apnea syndrome (OSAS) is a sleep disorder characterized by partial or complete obstruction of the upper airway during sleep, leading to disrupted breathing patterns [1,2]. It is relatively common, affecting approximately 2-4% of adults in the general population. While OSAS can occur at any age, it is more prevalent in middle-aged males [3]. Several risk factors contribute to the development of this condition, including obesity ($BMI > 30$), upper airway obstructions such as nasal turbinate hypertrophy, septum deviations or nasal polyps, tobacco and alcohol consumption, and the presence of craniofacial anomalies like maxillary hypoplasia or micrognathia. The consequences of OSAS are significant, impacting various aspects of an individual's life. Daytime sleepiness, impaired vigilance, and cognitive dysfunction are common symptoms that affect a person's ability to perform daily activities

effectively. These symptoms also contribute to an increased risk of motor vehicle accidents, occupational injuries, and a lower overall quality of life [4]. The diagnosis should be based on the patient's medical history and a clinical and instrumental examination. The Epworth Sleepiness Scale, Berlin questionnaire, and STOP-Bang questionnaire guide the clinical assessment. The most accurate diagnostic examination for OSAS is polysomnography, performed in a sleep laboratory. Polysomnography involves continuous nocturnal recordings, including measurements of various parameters such as electroencephalogram, electrooculogram, electromyography, nasal and oral airflow, respiratory effort, oxygen saturation, body position, and electrocardiogram. Moreover, considerable evidence suggests that OSAS is independently associated with cardiovascular disease, cerebrovascular disease, and type 2 diabetes [5,6]. Thus, early diagnosis and effective management of OSAS are crucial for reducing the risk of these comorbidities. Continuous positive airway pressure (CPAP) is the treatment of choice for mild, moderate, and severe OSAS and should be offered as an option to all patients. Alternative therapies may also be proposed depending on the severity of the OSAS and the patient's anatomy, risk factors, and preferences [7]. In recent years, oral appliances (OAs) have emerged as a popular alternative treatment for OSAS and snoring [8]. OAs, specifically mandibular advancement devices (MADs), are recommended for patients with mild to moderate OSAS who prefer them over CPAP or who do not respond well to CPAP [7]. MADs cover the upper and lower teeth,

holding the mandible in an advanced position, typically forward by 5 to 11 mm (50-75% of maximal protrusion) [4], to improve the patency of the upper airway during sleep by enlarging it and/or by decreasing its collapsibility. Anterior movement of the tongue or mandible can increase the cross-sectional airway size and improve upper airway muscle tone [9]. Traditionally, the production of oral devices involved conventional impression taking and manual construction of the appliance. However, with advancements in computer technology and dental processing, a fully digital workflow based on CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) technology has become feasible [10]. Intraoral scanners (IOS) have become widely available and offer an efficient and accurate alternative to conventional impressions. Numerous studies have reported that current intraoral scanners demonstrate clinically valuable accuracy, at least comparable to conventional impression-based approaches. Whereas in vivo studies report that full-arch impressions are associated with distortion phenomena for single-tooth restorations or fixed partial prostheses of up to 4-5 elements, the scientific literature deems the accuracy of optical impressions to be satisfactory and similar to conventional impressions. However, for more extensive restorations, such as partial fixed prostheses with more than 5 elements or full-arch prostheses on teeth or implants, intraoral scanning might not offer the same level of precision as conventional impressions [11,12]. Regarding orthodontic purposes, digital models appear to be as reliable as traditional plaster models, and full-arch impressions

obtained using IOS can replace traditional ones [13-15]. Although the precision of these complete-arch scans is considered inferior to that obtained using conventional impressions, reports also show that IOS is sufficiently accurate for fabricating occlusal devices, such as Michigan splints, in a fully digital workflow [16,17]. Currently, no study in the literature evaluates the use of optical impressions in the production of MADs used in OSAS treatment, and overall, no study has investigated aspects such as the accuracy, fit, and comfort of MADs in relation to device manufacturing procedures. This study aims to assess the clinical accuracy of MADs produced using CAD/CAM technology with two different impression techniques: conventional impression taking and intraoral scanning. By comparing the two approaches, researchers hope to shed light on the potential benefits and limitations of using digital impressions to produce MADs for patients with OSAS.

1.2 MATERIALS AND METHODS

This research study focused on evaluating the clinical parameters of mandibular advancement devices (MADs) produced using two different impression techniques: intraoral scans and digitalization of traditional plaster models. The aim was to identify which methods might offer the best accuracy for MAD fabrication. The intraoral scan and traditional plaster model techniques were utilized during the experimental phase to produce the MADs for each volunteer. These devices were then thoroughly evaluated based on several critical clinical parameters. The ease of insertion and

removal of the MADs was assessed to determine how user-friendly and manageable they were for the volunteers. Adequacy of shape and margins examined the precision and accuracy of the devices in fitting the individual's dental anatomy. Retention, another crucial parameter, gauged how well the MADs stayed in place during use, ensuring optimal effectiveness during sleep. Comfort, a significant aspect, was evaluated to ascertain the overall satisfaction and tolerance of the participants with each MAD, aiming to identify the technique that provided a more comfortable fit. Four adult healthy volunteers were recruited as participants from among the patients attending a private dental office. Patients with contraindications to oral devices, such as periodontal disease, dental mobility, poor tooth retention, inadequate temporomandibular joint range of motion, or extensive tooth loss, were excluded from the study. All volunteers had lost no more than one tooth, excluding third molars, during their lifetime, making them ideal candidates for the research. In this study, two impressions of both dental arches were taken from each patient to compare the effectiveness of conventional and digital impression techniques. The first set of impressions was obtained using a traditional technique. Monophasic impressions were taken using polyvinyl siloxane, and standard impression trays were utilized to capture the dental arches' detailed morphology. The conventional method involves carefully inserting the tray into the patient's mouth and allowing the impression material to accurately set and capture the teeth and surrounding structures. The second set of impressions was obtained

using a state-of-the-art digital impression system. The CEREC Omnicam® intraoral scanner was employed with CEREC Ortho SW 1.2® software (Dentsply Sirona; North Carolina, USA). The intraoral scanner is a handheld device with advanced optical technology that allows for the non-invasive capture of dental arches in a three-dimensional digital format, providing real-time visualization and accurate digital models of the patient's teeth and surrounding oral structures.

The intermaxillary relationship was recorded in maximum intercuspation while acquiring both conventional and digital impressions. Furthermore, to ensure optimal fit and function of the MADs, the patient's maximal mandibular protrusion was carefully recorded. This measurement considered the distance from the upper right central incisor to the lower right central incisor during mandibular protrusion movement, according to the oral devices manufacturer's indications. Once the conventional and digital impressions of the patient's dental arches were obtained, two Narval CCTM dental devices (Resmed Inc., California, USA) were produced for each patient using computer-aided design/computer-aided manufacturing (CAD/CAM) techniques. The Narval CCTM devices are bi-block MADs made from semi-rigid, biocompatible polymer plastic materials. For the devices produced from the traditional impressions, a skilled dental technician transformed the impressions into plaster models. These plaster models were then scanned to create accurate digital models. These digital models served as the basis for designing the mandibular advancement devices through CAD/CAM processes. A double-blind procedure was

employed for the testing phase to ensure unbiased evaluation. An expert dental clinician with specialized training in dental sleep medicine, unaware of the type of MAD being used, delivered and evaluated the two devices for each patient. Additionally, the patients were unaware of the type of device they were testing. To maintain anonymity during the evaluation process, a second operator assigned a unique code to each test device. This coding system ensured that the evaluator and patients could not determine which MAD was conventional and which was digital. After receiving the MADs, the volunteers were instructed to wear them for several nights during sleep. They were then asked to provide feedback on their experience, particularly regarding the level of comfort achieved and any unexpected events they encountered while using the devices. The devices consisted of two parts, i.e., an upper and a lower splint, interconnected by exchangeable rods of different lengths. Although five design variations were available covering a range of patient needs and anatomical constraints, only one was selected for this study (“facial band” for both the upper and the lower jaw) to ensure the devices were comparable. However, following the manufacturer’s indications and based on the clinical evaluations, one patient was given different designs due to his particular dental morphology (“incisors full coverage” for both the upper and the lower jaw for the digital device; “incisors full coverage” for the lower jaw and “facial band” for the upper jaw for the analogic device). The amount of mandibular advancement was set at 60% of maximum

protrusion for all the patients. The devices were fabricated using CAD/CAM technology, starting with scanned plaster casts and optical impressions of the dental arches. Computer-aided design (CAD) enables a high degree of customization to suit the complex dental anatomy of each patient. A virtual articulator was used in this stage. Computer-aided manufacturing (CAM) using selective laser sintering of a biocompatible polymer material (polyamide) guarantees consistent, industrial-strength manufacturing. This study used the Cerec Omnicam® intraoral scanner with Cerec Ortho SW 1.2® software (Dentsply Sirona; North Carolina, USA) to acquire full-arch digital impressions. A full-arch guided scanning procedure was used, requiring the operator to wield the intraoral scanner throughout the process. The powder-free scanner relies on optical triangulation with video sequencing using white LED for image acquisition. The same expert operator performed all digital scanning procedures. Using Cerec Omnicam® with the Cerec Ortho® software, a 3D digital model is generated and available directly after imaging, and the integrated model analysis tools allow quick access to the clinical information. The scan data were later exported as STL digital files and sent to the laboratory in this format, attached to the order form, through the Narval Easy online portal. To compare the MADs produced starting from the two different impression techniques, a list of clinical parameters was drawn up to test the quality of the devices. The literature was searched to identify objective clinical parameters that could define the clinical fit of oral appliances, but poor results were found. Most published studies

concern fixed prostheses or use in vitro measurements to evaluate device accuracy. Only a few studies suggested clinical parameters that may be used to evaluate the accuracy of oral devices, such as orthodontic appliances or occlusal devices [17-21]. No study that evaluated the clinical accuracy of MADs was found. Supplementing the articles found in the literature, a list of parameters was established with univocal definitions. Numerical scores were provided for each parameter based on objective criteria. Table 1 shows the list of parameters and scores. Statistical analysis was conducted using a paired t-test to compare the scores obtained using the different devices for the five parameters considered (insertion, removal, adequacy of margins and shape, retention, and comfort). The statistical analysis aimed to report differences between the scores obtained by the two groups of devices for each parameter analyzed. A comprehensive assessment of each device was also carried out, considering the total score obtained by summing the parameter scores. The comprehensive score was compared between the devices using the same statistical analysis method.

CLINICAL PAREMETER	SCORE		
	0 (low)	1 (acceptable)	2 (optimum)
Insertion	It is not possible to obtain complete insertion and the proper positioning of the device	The device can be placed with difficulty, or it is necessary to apply high or too little pressure, or it is necessary to make adjustments on the device.	The device can be easily placed, with no need for adjustments (snap fit)
Removal	Difficulties occur in removing the device / the patient cannot remove the device independently	The device can be easily removed from oral cavity but only after adjustments	The device can be easily removed by the patient with no need for adjustments
Adequacy of margins and shape	Inaccuracies or areas of excessive pressure on tissues are found, or the patient reports discomfort wearing the device as a consequence of excessive pressure on the teeth or gums	Mild inaccuracies are found, or the device can be worn without discomfort after adjustments	Perfect congruence between shape/margins of the device and patient's tissues
Retention	Retention of the device is lacking in both the upper and lower jaws during mouth opening and closing	The device dislocates either the upper or the lower jaw during mouth opening and closing	The retention of the device is sufficient to allow usual oral functions (such as swallowing, mouth opening and closing)
Comfort	The patient struggles with the device and cannot get used to it	The patient feels slight discomfort when wearing the device but bears it	The patient feels comfortable wearing the device

Table 1. Parameters and scores

1.3 RESULTS

Tables 2 and 3 show the single parameter scores obtained by each device and the total score for each device. None of the devices were found during the clinical evaluation to cause side effects (such as gum soreness or crushing), and none of the patients reported side effects or discomfort after wearing them for a few nights. Paired t-tests were conducted to test for statistically significant differences between

the two groups of devices for both total scores and single parameters (Figure 1). The tests used a 95% confidence level (definition of statistical significance: $p < 0.05$).

Parameter	Patient 1		Patient 2		Patient 3		Patient 4	
	Analog	Digital	Analog	Digital	Analog	Digital	Analog	Digital
Insertion	2	2	2	1	1	2	1	2
Removal	2	2	2	1	1	2	1	2
Adequacy of margins and shape	2	2	1	1	2	1	2	2
Retention	1	2	2	2	1	2	1	2
Comfort	2	2	1	0	2	1	2	2

Table 2. Scores obtained from the clinical examination of the devices

Parameter	Total		Arithmetic mean	
	Analog	Digital	Analog	Digital
Insertion	6	7	1.5	1.75
Removal	6	7	1.5	1.75
Adequacy of margins and shape	7	6	1.75	1.5
Retention	5	8	1.25	2
Comfort	7	5	1.75	1.25
TOTAL SCORE (objective parameters)	24	28		
TOTAL SCORE (including patient's comfort)	31	33		

Table 3. The total of the scores and arithmetical means obtained from the two different device groups

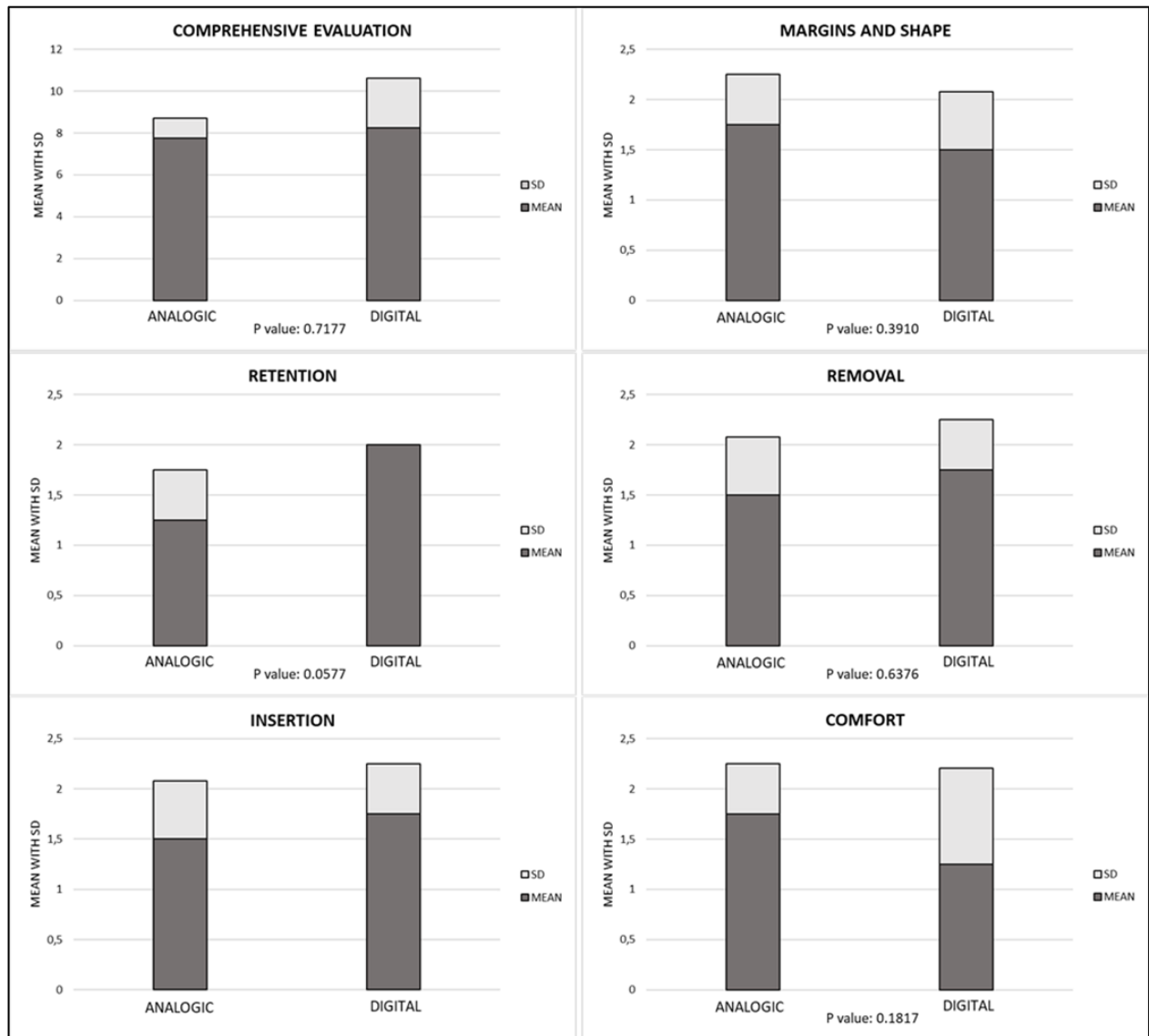


Figure 1. Comprehensive evaluation and single parameters: means with standard deviations

1.4 DISCUSSION

This study evaluated the clinical accuracy of MADs produced from digital and traditional impressions. The effectiveness of the devices for the treatment of OSAS was not evaluated, although considerable evidence exists supporting the effectiveness of MADs in this setting. In the existing literature, no studies have

specifically investigated aspects such as accuracy, fit, and comfort of mandibular advancement devices in relation to device manufacturing procedures. These aspects hold significant importance in clinical practice, as poorly fitting devices could waste time and resources for dental clinics and laboratories. Moreover, ill-fitting devices may negatively impact patient comfort and compliance, ultimately affecting the overall effectiveness of the treatment. The MAD production process traditionally involves taking impressions using alginate or elastomeric materials. However, technological advancements now enable specialized laboratories to work directly from digital scans of dental arches. In modern clinical practice, full-arch scans are used for MAD fabrication and orthodontic purposes, such as diagnosing and producing orthodontic appliances. While some studies have examined the accuracy of intraoral scans, they have primarily been laboratory-based and focused on in vitro measurements. Only a few studies have conducted clinical assessments on the accuracy of oral appliances produced from full-arch scans, specifically orthodontic appliances or occlusal devices, and no such study has evaluated MADs. Therefore, the current study's contribution lies in developing a comprehensive set of clinical parameters used to assess the fit of intraoral appliances and facilitate comparisons between different devices. The established parameters were supplemented with a scoring system and detailed definitions to make them objective and unambiguous. Furthermore, the devices were clinically tested using a double-blind procedure to avoid conditioning of any kind. One of the essential achievements of this study was

the production of two different MADs for each patient—one based on an optical scan and the other from a traditional impression. This comparative approach allowed for a comprehensive evaluation, considering potential anatomical variations between patients. It is crucial to assess how these differences might affect the clinical fit and retention of the MADs. By making these direct comparisons, the study aimed to provide more robust evidence for the clinical use of intraoral scanners in MAD fabrication. The primary limitation of the present study is the relatively small number of patients included in the research, which affects the statistical power and generalizability of the results. However, the study has laid the groundwork for future investigations, and the aspects examined herein could serve as a basis for more extensive and robust statistical analyses in subsequent studies with larger patient cohorts. Despite the limitations, the current study demonstrates that using an intraoral scanner can provide adequate accuracy for producing mandibular advancement devices (MADs). This finding suggests that intraoral scanners may be a viable and reliable option for clinical practice, potentially enhancing the available evidence in dental sleep medicine. However, it should be noted that the cost of producing two devices per patient, as required for the study's design, makes this approach more suitable for scientific research purposes rather than routine clinical practice. Nevertheless, some valuable conclusions can still be drawn from the present study. First, all the tested devices exhibited at least an acceptable level of accuracy, with none of the devices considered inadequate in any parameter. While one device

based on an optical impression received a negative patient comfort evaluation, this aspect is subjective, and the other parameters were deemed more meaningful. Overall, both impression techniques produced satisfactory results, suggesting they can be suitable for clinical practice. No statistically significant differences were found in the comprehensive evaluation (total score) or individual parameters after comparing the two groups of devices. This indicates that the accuracy of the MADs fabricated from optical impressions was similar to that of conventional impressions. Furthermore, it is worth noting that all the devices produced from optical impressions received the maximum score for retention. This finding is particularly noteworthy because retention is a critical aspect of MADs. Poor retention can lead to patient discomfort and compromise the treatment's effectiveness. The ability of the devices from optical impressions to achieve maximum scores for retention suggests their general high-quality construction and potential clinical utility. A deficiency in parameters such as comfort or adequacy of margins can often be rectified through chairside adjustments. In contrast, poor retention is a trickier problem to solve, suggesting poor general quality of the device. Insufficient retention can, in some cases, even make it necessary to remake the device.

1.5 CONCLUSIONS

The findings of the current study indicate that mandibular advancement devices (MADs) produced using CAD/CAM techniques, whether starting from optical digital

impressions or conventional polyvinyl-siloxane impressions demonstrate comparable clinical fit and accuracy. These results suggest that a fully digital workflow can be effectively utilized for MAD fabrication in clinical practice, offering the possibility of obtaining high-quality devices with excellent clinical fit, similar to those produced from conventional impressions. The CAD/CAM technology adoption in MAD fabrication has shown promising outcomes, providing a more streamlined and efficient approach to device production. The digital workflow allows for precise customization and better adaptation to the patient's dental anatomy, potentially improving patient comfort and treatment efficacy. Additionally, the digital process reduces the reliance on physical materials and manual labor, contributing to cost savings and shorter turnaround times for device delivery. While the study's results are encouraging, it is essential to acknowledge the need for further research involving larger patient cohorts. Expanding the sample size and including a more diverse patient population would help establish more statistically significant conclusions. Conducting multicenter studies with standardized protocols could also enhance the reliability and generalizability of the findings. Incorporating additional outcome measures could provide a comprehensive assessment of the MADs' performance and patient satisfaction. Long-term follow-ups to evaluate treatment efficacy, adherence, and potential side effects would offer valuable insights into the devices' overall clinical effectiveness. Furthermore, exploring the cost-effectiveness of the digital workflow compared to traditional methods would benefit healthcare providers and patients.

Understanding the economic implications could lead to more widespread adoption of CAD/CAM techniques in dental sleep medicine.

1.6 SYSTEMATIC REVIEW

In addressing the literature review about sleep medicine, we investigated a possible correlation between chronic periodontal disease in adults and obstructive sleep apnea syndrome [22].

1.6.1 Introduction

Obstructive sleep apnea (OSA) is a respiratory disorder characterized by recurrent episodes of an obstruction of the upper airways during sleep called apneas (if the airways are completely obstructed) or hypopneas (if the obstruction is only partial) [23]. Recent epidemiological studies show a high prevalence of this disease, with significant health, social, and economic consequences [24]. It is estimated that it affects 10% to 50% of the general population, with some subgroups at a higher risk [25]. However, the data may be underestimated due to the difficulty of diagnosing this condition [26]. These pathological respiratory occurrences may be followed by transient arousals that restore the upper airway's patency.

In most cases, the awakenings are not complete, and the patient remains unaware of it. These alterations induce oxidative stress, sympathetic activation, and metabolic dysregulation [27]. Periodontitis is a chronic infection and an inflammatory disease caused by bacterial pathogens that initiate an inflammatory response by the host [28]. The synergetic effect of bacterial toxins and host immune response results in the destruction of periodontal tissues manifested clinically as loss of alveolar bone, progressive loss of periodontal attachment, pocket formation, and, ultimately, tooth loss [29]. Periodontitis can affect subjects of any age, from children still in primary dentition to the elderly. The prevalence of periodontitis varies with age: It is <1% in pediatric age but can reach 43% in the adult or geriatric population [30]. There is convincing evidence in the literature about an association between periodontitis and other systemic diseases such as ischemic cardiovascular disease, type 2 diabetes mellitus, and obstetric complications (birth of premature and/or underweight babies).

Similarly, for OSA, there is scientific evidence supporting an association with cardiovascular diseases, cerebrovascular diseases, gastroesophageal reflux, and type 2 diabetes mellitus [31]. In recent years, there has also been increasing interest in the potential association between periodontitis and OSA, as they are frequent disorders that have common risk factors, and they are both associated with systemic inflammation and cardiovascular morbidity [32]. This correlation could imply

coexisting periodontitis as an essential mediator of inflammation in OSA or vice versa. The possibility that coexisting periodontitis may still be an unknown confounder in the relationship between OSA and cardiovascular morbidity needs consideration. This systematic review aims to evaluate whether there is scientific evidence regarding the association between periodontitis and OSA by analyzing the available literature.

1.6.2 Materials and Methods

The protocol for this systematic review was designed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [33]. The proposed focus question was: “Is there a relationship between OSA and periodontitis, considering the existing scientific literature?”

Inclusion/exclusion criteria

Participant, Intervention, Comparison, and Outcome (PICO) criteria were used in this systematic review. The PICO system was designed to answer the following question: “Is there a relationship between OSA and periodontitis, considering the existing scientific literature?” (P) Population: human male and female adults; (I) Intervention: comorbidity of OSA syndrome and periodontal disease; (C) Control: human adults not affected by both OSA and periodontal disease; (O) Outcome: any relationship between OSA and periodontitis.

Epidemiological studies concerning the relationship between OSA and periodontitis were included. Male and female subjects over the age of 18 affected by both OSA and periodontitis were considered. It was chosen to consider only the studies in which diagnosis of periodontitis was formulated following the classification systems of periodontal and peri-implant diseases and conditions resulting from the 2017 World Workshop organized jointly by the American Academy of Periodontology and the European Federation of Periodontology [34] or the classification system of periodontal diseases of 1999 [35]. In these articles, the authors used parameters such as probing depth (PPD), clinical attachment level (CAL), plaque index (PI), and bleeding on probing (POB) to diagnose periodontal disease. On the other hand, the diagnosis of OSA had to be done by polysomnography (PSG) conducted in a sleep laboratory or at home with portable devices (HST). Studies that determined the risk of OSA through the evaluation of the Mallampati index [36], tonsillar hypertrophy, and the use of validated questionnaires such as Epworth Sleepiness Scale (ESS) [37], Berlin questionnaire [38], and STOP-BANG questionnaire [39] were also taken into consideration.

This review included prospective and retrospective longitudinal studies, cohort studies, and case-control studies, in human adults, with no restrictions on sample size and geographical location, published between 2000 and December 2021. Samples with non-OSA and non-periodontitis subjects represented the comparison group. Clinical cases, systematic reviews, review articles, abstracts, animal studies, and

publications not in English were excluded from this review. Studies that did not directly assess the relationship between OSA and periodontitis were excluded.

Search strategy and selection process

To ensure a complete and exhaustive evaluation of the scientific evidence, a bibliographic search was performed using electronic databases with the contribution of a clinician (EM). The search was conducted on MEDLINE/PubMed to identify articles published from 2000 to December 2021. Two limitations were applied to the literature search: human studies and year of publication. The following databases were searched using keyword terms and subject headings to represent sleep apnea and periodontal disease. The search strings for identifying the studies are shown in Table 4. The first search strategy (# 1 search MEDLINE), relating to the terms MeSH and Free Terms descriptors of OSA, found 55,954 publications, and the second search (# 2 search MEDLINE), relating to the MeSH terms descriptors of periodontitis, identified 91,449 citations. The joint use of the two searches with the Boolean operator “AND” produced 70 articles.

Step	Keywords	Citations
#1	sleep apnea syndromes [MeSH Terms] or obstructive sleep apnea [MeSH Terms] or obstructive sleep or obstructive sleep apnea syndrome or obstructive sleep apnea hypopnea syndrome or OSAHS or OSA or sleep disordered breathing	55.954
#2	periodontitis [MeSH Terms] or periodontal disease [MeSH Terms] or gingival disease [MeSH Terms] or periodontal attachment loss [MeSH Terms] or alveolar bone loss [MeSH Terms] or gingival recession [MeSH Terms] or periodontal pocket [MeSH Terms] or tooth loss [MeSH Terms]	91.449
#3	1 AND 2	70

Table 4. Search strategies

The literature search identified studies potentially eligible for inclusion in the systematic review. The selection of articles to be included in the review was carried out in several stages. The first phase made it possible to identify the works of potential interest by reading the title and abstract of each individual contribution; in the second phase, the reviewers examined the full text of the selected articles and identified the pertinent ones. Two reviewers (GR and EM) independently analyzed and evaluated the identified studies to ensure an objective, transparent, and reproducible literature evaluation. Any discrepancy in the work evaluation outcome was discussed and resolved by consensus.

Data extraction

A customized Excel spreadsheet was prepared to organize and collect the primary information of the studies included in the systematic review. While one reviewer extracted the data, another verified the extracted data. Any disagreements were resolved through discussion between the two.

From each included publication, information was extracted relating to the surname of the first author, the country in which the study was carried out, the article's year of publication, study design, reference population (sample size, females, males, and mean age), diagnostic criteria of OSA and periodontitis, study objective, study results, and authors' conclusions.

Quality assessment

Before conducting the analysis, to explore the study result variability (heterogeneity), it has been hypothesized that the effect size may differ in relation to the methodological quality of the studies. An independent evaluation was conducted for each article to define the validity of the studies selected during the full-text phase.

The quality of the studies that met the inclusion criteria was independently assessed by two authors using the Newcastle–Ottawa Scale (NOS) based on study type. The NOS was then used to evaluate nonrandomized studies to determine the risk of bias in case-control studies [40]. In contrast, cross-sectional observational studies were assessed using an adapted form of NOS developed by Herzog et al. [41]. These tools

allow the evaluator to assign a quality score at three levels (“good”, “fair,” or “poor”) based on the consideration of different elements. The tool for case-control studies evaluates 8 elements divided into 3 groups: selection of study groups, comparability of groups, and exposure assessment. The tool for cross-sectional studies evaluates 7 elements divided into 3 groups: selection of study groups, comparability of groups, and results.

A Star system was used, which provides up to a maximum of 9 for case-control studies and 10 for cross-sectional ones. Studies are therefore classified into 3 groups of bias: low (score >8), medium (score 6–8), and high risk (score <6). The high risk of bias results in a poor-quality evaluation, while the low risk implies a good-quality assessment. Therefore, the greater the risk of bias, the lower the study quality. If the ratings differed, the authors discussed the findings to reach an agreement.

1.6.3 Results

Moher et al. proposed the flowchart to outline the phases of including the articles in the PRISMA document [Figure 2] [33].

Through the bibliographic search on PubMed, 70 articles were identified, published between 2000 and December 2021, while only one article was identified through the search in scientific journals. In the first screening phase, 46 articles were excluded because they did not meet the inclusion criteria. In the full-text screening phase, 10 studies were excluded because their full text was unavailable or did not meet the

eligibility criteria, while 14 studies were included. No relevant unpublished studies were identified.

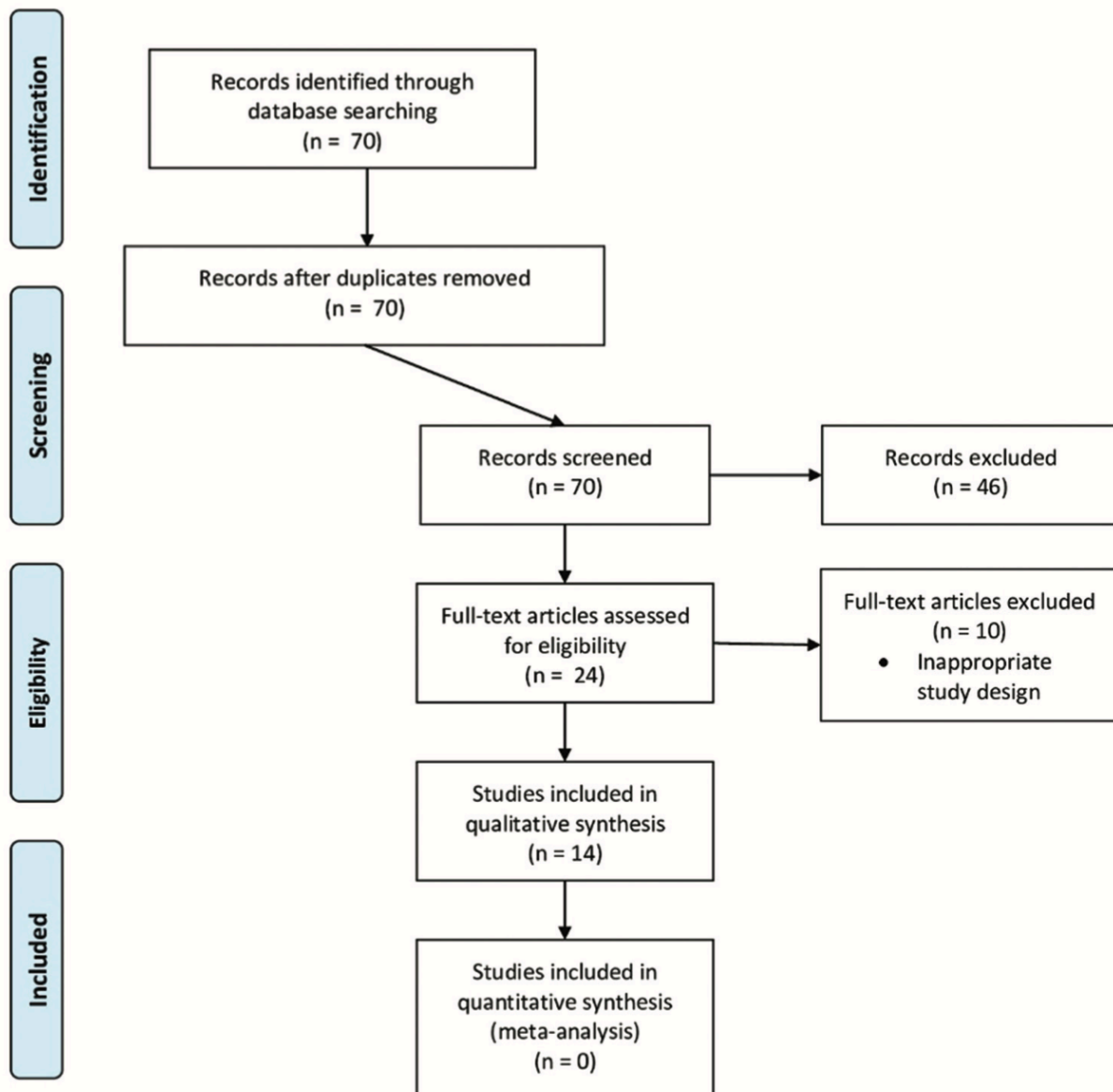


Figure 2. Preferred reporting items for systematic reviews and meta-analyses 2009 flow diagram [33].

Risk of bias in studies

The mean NOS score for the case-control studies was 5.2 (range = 4–7) [Table 5]. The risk of bias was found mainly in the representativeness of cases, in the definition of controls, in the design and analysis of the study, and in the nonresponse rate. The mean NOS score for the cross-sectional studies was 7.8 (range = 7–10) [Table 6]. The most significant risk of bias was found in nonresponders, sample size, study design, and control of confounding factors. Among the case-control studies, four had a high risk of bias as they scored <6 stars, while two had a medium risk of bias with a score between 6 and 8. Three cross-sectional studies with scores >8 stars found a low risk of bias, while the remaining five scored between 6 and 8, indicative of a medium risk of bias. Based on the risk of bias assessment tools, three [42-44] studies achieved “good” quality, seven [45-51] “fair” quality, and four [50,52,53] “poor” quality.

Is the case definition adequate?	Representativeness of the case	Selection of controls	Definition of controls	Comparability of cases and controls	Ascertainment of exposure	Same method of ascertainment for cases and controls	Nonresponse rate	Risk of bias
★		★	-	★★	★	★	-	Medium
★	-	★	-	-	★	★	-	High
★	-	★	-	-	★	★	-	High
★	-	★	-	-	★	★	-	High
★	★	★	-	★★	★	★	-	Medium
-	★	★	-	★★	-	★	-	High

Table 5. Newcastle-Ottawa Scale for case-control cases

Representativeness of the sample	Sample size	Ascertainment of exposure (risk factor)	Nonrespondents	Comparability of subjects in different groups	Assessment of outcome	Statistical test	Risk of bias
-	★	★	-	★★	★★	★	Medium
★	-	★★	-	-	★★	★	Medium
★	★	★★	-	-	★★	★	Medium
★	-	★★	★	★★	★★	★	Low
★	★	★★	★	★★	★★	★	Low
★	★	★★	-	-	★★	★	Medium
★	-	★★	★	★★	★★	★	Low
★	★	★	-	★★	★★	-	Medium

Table 6. Newcastle-Ottawa Scale for Cross-sectional Studies

Results of syntheses

Table 7 summarizes the main findings of the articles included in this systematic review. Statistical synthesis of the results was not possible as study designs, participants, interventions, and outcomes were variable between the included studies; therefore, the author of the present paper focused on the description of the studies, their results, their applicability, and their limitations, preferring qualitative synthesis to meta-analysis. Six of the 14 selected studies were case-control [45,46,52-55], and eight were cross-sectional [42-44,47-51]. The studies included in the review were representative of a total sample of 43,773 individuals. The sample size in the studies ranged from 52 to 29,284 adult subjects. The age ranged from 21 to 85 years, and 56% were male subjects. Three of the studies came from the United States [43,46,50], four from Turkey [43,52-53], while the rest came from Australia [51], Taiwan [55], Brazil [49], Colombia [48], Jordan [42], Korea [44], and China [47]. All studies evaluated the association between periodontitis and OSA. Seven studies

Study design	Population	Diagnosis or risk for OSA	Periodontitis assessment	Objective	Results	Authors' conclusion	Quality of the studies
Cross-sectional	<i>n</i> =93 subjects All males age range: 24–35 years 19 - OSA 74 - non-OSA	PSG at home according to AASM criteria	CAL, PPD, BOP	OSA-periodontitis association; dose–response relationship	Prevalence of OSA: 32.5%. BOP and CAL significantly higher in the OSA group. No significant difference for PPD in the two groups. Weak but positive correlation between OSA severity and that of periodontitis	Significant association between OSA and periodontitis. Low SaO ₂ could be a predictive index of periodontal disease	Fair
Cross-sectional	<i>n</i> =199 subjects 107 males; 92 females Age range: 30–85 years (mean age 49 years)	PSG at sleep clinic according to AASM criteria	CAL, PPD, REC	OSA-periodontitis association	Prevalence of periodontitis: 62.3%. Significant association between periodontitis and mild OSA (<i>P</i> =0.041)	Significant association between periodontitis and mild OSA, more frequent in women with hypertension and hypertensive cardiomyopathy. Significant association between periodontitis and OSA (moderate or severe) in men with hypertension or hypertensive cardiomyopathy	Fair
Case–control	<i>n</i> =163 subjects 41 females; 122 males Age range: 30–85 years (mean age 45±9 years) 83 - OSA 80 - non-OSA	PSG according to AASM criteria	PI, BOP, PPD, CAL, GI, GCF, IL-1β, TNF-α, hs-CRP, serum hs-CRP	OSA-periodontitis association; dose–response relationship	Prevalence of periodontitis in the OSA group significantly higher than in the control (<i>P</i> <0.001). Periodontal clinical parameters and GCF IL-B concentrations higher than in the controls. Prevalence of severe periodontitis higher in the severe OSA group than in mild OSA, but no significant difference	Higher prevalence of periodontitis and higher levels of GCF IL-B and serum hs-CRP	Fair
Case–control	<i>n</i> =52 subjects 20 females; 32 males Age range: 21–64 years 17 - mild/moderate OSA 22 - severe OSA 13 - non-OSA	PSG according to AASM criteria	PI, BOP, PPD, CAL, salivary and serum IL-6, TNF-α, OPG, sRANKL, APELINA	OSA-periodontitis association	Change in bacterial plaque composition in cases. Correlation between OSA and severity of periodontal indices significantly higher salivary levels of IL-6 and apelin in cases than in control (<i>P</i> <0.05). No significant difference in both groups for other biomarkers serum significant association between salivary IL-6 levels and OSA severity indices	The increase in salivary concentrations of IL-6 and apelin may have an impact or be due to periodontitis in OSA patients	Poor
Cross-sectional	<i>n</i> =108 obese subjects with class III malocclusion 85 females; 23 males Age range: 30–60 years	Berlin questionnaire and ESS	PPD, CAL, BOP	OSA-periodontitis association	No association between <i>P</i> and OSA risk	There is no association between periodontitis and OSA risk in class III obese patients	Fair

Study design	Population	Diagnosis or risk for OSA	Periodontitis assessment	Objective	Results	Authors' conclusion	Quality of the studies
Cross-sectional	<i>n</i> =296 subjects All males Age range: 30–60 years (mean age 40 years)	Berlin questionnaire	PPD, CAL, BOP, GI, PI	OSA-periodontitis association; dose–response relationship	Patients with high risk for OSA showed higher PPD and CAL than patients with low risk for OSA	Positive association between periodontitis and high risk of OSA. Periodontitis in patients with high risk for OSA was more generalized and severe	Good
Case–control	<i>n</i> =50 subjects 20 females; 30 males Age range: 21–64 years 17 - mild/moderate OSA 20 - severe OSA 13 - non-OSA	PSG at sleep clinic according to AASM criteria	PPD, CAL, BOP, PI, salivary and serum MMP-8, proMMP-2, MMP9, TIMP-1, MPO, NE	OSA-periodontitis association	Periodontal parameters were higher in the severe OSA group but without statistically significant differences (<i>P</i> >0.05). Serum MMP-9 was significantly lower in severe OSA than in control (<i>P</i> =0.046). Salivary levels of NE and proMMP-2 were significantly lower in the OSAS groups compared to the control group (<i>P</i> <0.05)	There is no pathophysiological link between the severity of OSAS and clinical periodontal status via neutrophil products and MMPs	Fair
Cross-sectional	<i>n</i> =12,469 subjects 7473 females; 4996 males Age range: 18–74 years 1783 - AHI 0 7039 - AHI 0.1–4.9 2298 - AHI 5–14.9 1349: AHI ≥15	PSG at home according to AASM criteria	PPD, BOP, REC, CAL	OSA-periodontitis association; dose–response correlation	Dose–response relationship between prevalence of severe periodontitis and severity of AHI. This correlation was stronger in the subgroup 18–34 years	Significant association between OSA e periodontal disease	Good
Cross-sectional	<i>n</i> =100 subjects 9 females; 91 males Age range 28–79 years (mean age 52.6 years) 21 - OSA mild 19 - OSA moderate 34 - OSA severe 26 - non-OSA	PSG according to AASM criteria	CAL, PPD, REC, % sites with plaque, % sites with PD ≥ 5 mm, % sites with CAL ≥ 3 mm	OSA-periodontitis association; dose–response relationship	Prevalence of periodontal disease: 73%. No significant difference in the prevalence of periodontitis between the different grades of AHI and with the periodontal indices	OSA was not significantly associated with the presence of moderate or severe periodontitis except for % of sites with plaque	Fair
Case–control	<i>n</i> =52 subjects 20 females; 32 males Age range: 21–64 years 17 - mild/moderate OSA 22 - severe OSA 13 - non-OSA	PSG at sleep clinic according to AASM criteria	CAL, PPD, BOP, PI, number of teeth present, salivary concentration of IL-1β, IL-6, IL-21, IL-33, PTX3	OSA-periodontitis association	IL-6 and IL-33 were significantly higher in OSA group than controls (<i>P</i> <0.05). No significant difference between all groups in IL-1β, IL-21, and PTX3 concentrations. Significant correlation between CAL and IL-21. Significant correlation between CAL, PD, and OSA severity indices	OSA does not have a prominent effect on IL-1β, IL-21, and PTX3 levels. OSA, independently of its severity, could increase IL-6 and IL-33 levels. No pathophysiological link between OSA severity and periodontal status via salivary cytokines	Poor

Table 7. Data extraction (continued on the following page)

Study design	Population	Diagnosis or risk for OSA	Periodontitis assessment	Objective	Results	Authors' conclusion	Quality of the studies
Case-control	n=154 subjects 93 females; 61 males Mean age 61 years 50 - severe or moderate periodontitis 104 - gingivitis or mild periodontitis	STOP-Bang questionnaire	PI, GI, CAL, BOP, PPD, REC, mobility, furcation involvement, radiographic bone loss	OSA-periodontitis association; dose-response relationship	HR-OSA: 60% of severe or moderate periodontitis patients and 28% of controls. Patients with severe or moderate periodontal disease had 4, 1 times greater odds of risk for OSA	Significant association between moderate or severe periodontitis and risk for OSA	Fair
Case-control	n=29,284 subjects 11,052 females; 18,232 males Mean age 47±15 years 7321 - OSA 21963 - controls	PSG	PPD ≥ 3 mm, BOP, tooth mobility, color and shape of gingiva tissue, radiographic bone loss	OSA-periodontitis association; periodontal treatment efficacy	Prevalence of periodontal disease in OSA cases: 33.8%. Prevalence of periodontitis in control group: 22.6%. Significant difference in the prevalence of OSA in subjects undergoing periodontal surgery compared to those not treated	Significant association between OSA and periodontitis	Poor
Cross-sectional	n=687 subjects 227 females; 460 males Age range: 47-77 years (mean age 55±6 years)	PSG at sleep clinic or at home	CAL, PPD, BOP, REC, PI, GI	OSA-periodontitis association; dose-response relationship	Prevalence of periodontitis: 17.5%. Prevalence of OSA: 46.6%. Prevalence of OSA in subjects with periodontitis: 60%	Significant association between OSA and periodontitis in subjects ≥ 55 years old. Dose-response association between periodontal disease, CAL, PPD, and increasing severity of OSA	Good
Cross-sectional	n=66 subjects 12 females; 54 males Mean age 54±12 years	PSG	CAL, PPD, BOP, REC, PI	OSA-periodontitis association	Prevalence of periodontitis: 77%-79%, depending on periodontal definition. Significant association between CAL and total sleep time	The prevalence of periodontitis in OSA patients was higher than in non-OSA	Fair

Table 7. (continued from the previous page)

[42-47,50] also evaluated the dose-response relationship, and one [55] assessed the evidence of the efficacy of periodontal interventions on the onset and severity of OSA. Eleven studies diagnosed OSA using PSG in a sleep clinic or the home sleep test [43-45,47,48,51-55], using AHI as the primary outcome, while three studies [42,46,49] used self-administered validated questionnaires. The types of questionnaires used in the studies were STOP [46], the Berlin questionnaire [42,49], and the ESS [49]. Only two studies [47,51] reported more than one outcome (AHI, mean SaO₂, minimal SaO₂, 4% ODI, rapid eye movement, and total sleep time). All studies assessed periodontitis using clinical (CAL, PPD, REC, PI, and BOP) and radiographic measures. Furthermore, four studies [45,52-54] evaluated inflammatory biomarkers in gingival crevicular fluid (GCF) and saliva.

Association between periodontitis and obstructive sleep apnea

All 14 studies evaluated the association between periodontitis and OSA. The prevalence of periodontitis ranged from 32.5% to 96.4% in case-control studies and from 15% to 85.2% in cross-sectional studies. The prevalence of OSA diagnosed by PSG or HST ranged from 20.4% to 75%, while the prevalence of OSA risk determined by validated questionnaires was 15%–81.5% in three studies. Eleven studies found a significant positive relationship between periodontitis and OSA. In four of these [46,47,55], the adjusted odds ratio (AOR) for periodontitis in patients with diagnosed OSA or at high-risk OSA was 3.69 (95% confidence interval [CI], 1.22–11.2), 1.75 (95% CI, 1.68–1.88; $P < 0.001$), 1.84 (95% CI, 1.18–2.87), and 4.1 (95% CI, 1.9–11.4) times greater than checks. Sanders et al. [43] found that the odds of periodontitis were 1.6 (95% CI, 1.1–2.2) in mild OSA and 1.5 (95% CI, 1.0–2.3) in moderate/severe OSA. Latorre et al. [48] reported higher odds (odds ratio = 1.37; 95% CI, 1.11, 2.68; $P = 0.041$) for periodontitis in mild OSA compared to non-OSA patients. This association was more frequent in women with hypertension or hypertensive cardiomyopathy, while periodontitis was associated with severe OSA in men with hypertension or hypertensive cardiomyopathy. Two case-control studies [52, 53] compared inflammatory biomarkers between cases with mild/moderate OSA and severe OSA and non-OSA controls. They found significant changes in plaque microbe composition ($P < 0.01$) and significantly higher levels ($P < 0.05$) of salivary interleukin (IL)-6 and salivary IL-33 in cases compared to controls. Salivary apelin was considerably higher

in the severe OSA group than in controls. Clinical attachment loss (CAL) and pocket depth (PD) were significantly correlated with the incidence and duration of apnea ($P < 0.05$) and with OSA severity indicators. Gunaratnam et al. [51] found that CAL was significantly correlated with one of the OSA indicators (total sleep time; $P < 0.05$). Gamsiz-Isik et al. [45] concluded that all periodontal clinical parameters, serum concentrations of hs-CRP, and GCF IL-1 β were significantly ($P < 0.05$) higher in patients with OSA than in controls. Al-Habashneh et al. [42] found an association between periodontitis and a high risk of OSA (HR-OSA) among patients who scored positive in two or more categories of the Berlin questionnaire. In contrast, three studies found no significant association between periodontitis and OSA. Nizam et al. [54] compared serum and salivary levels of collagenase (proMMP-2, MMP-9, and NE) in OSA and non-OSA patients, finding no pathophysiological link between OSA severity and periodontal status. Loke et al. [50] reported that OSA was not significantly associated with moderate or severe periodontitis. Multivariate logistic regression analysis predicting the association of moderate/severe periodontitis with AHI score, age, and smoking habit indicated a significant association with age but no significant association with OSA. Sales-Peres et al. [49] also found no statistically significant differences between periodontitis and the risk of OSA in obese patients as determined by the Berlin and ESS questionnaires.

Dose-response relationship in terms of severity and/or prevalence

The dose-response relationship was examined in seven studies. Sanders et al. [43] initially reported a correlation of severe periodontitis with AHI $\geq 15/h$ (OR = 6.9, 95% CI, 4.8, 10.0). After adjusting for confounding factors, the relationship remained significant but was attenuated in strength and no longer dose-response. Loke et al. [50] examined a possible dose-response relationship by stratifying the sample into four groups using the AHI as a variable. Although the percentage of subjects with moderate/severe periodontitis progressively increased with increasing severity of OSA, the finding was not statistically significant (Chi-square test, $P = 0.111$). AHI categories were significantly associated with the percentage of sites with plaque ($P = 0.037$) but not with bleeding on probing or CAL. The study concluded that there was no dose-response relationship between the prevalence and/or severity of periodontal disease and the severity of AHI. Gamsiz-Isik et al. [45] reported a higher prevalence of severe periodontitis in patients with severe-to-moderate OSA (52.2%) compared to mild OSA (31.2%), but there was no significant difference. Seo et al. [44] studied the dose-response relationship between OSA severity (AHI categories $<5/h$, $5-10/h$, $\geq 10/h$) and periodontitis. An increase in AHI was associated with a higher probability of CAL and PPD (AOR = 1.97; 95% CI, 1.07, 3.65) in subjects 55 and older. Chen et al. [47] found a positive but weak correlation between the severity of OSA and periodontitis. Ahmad et al. [46] reported an increase in moderate/severe periodontitis cases with an increase in affirmative responses on the OSA STOP

screening questionnaire. Two or more affirmative responses on the previously validated questionnaire indicated an HR-OSA. Twenty percent of moderate/severe periodontitis cases in their study reported an affirmative response to the OSA questionnaire, so the percentage increased to 47.6, and 100% as the number of responses increased to four. Finally, Al Habashneh et al. [42] identified HR-OSA cases among patients who scored positive in two or more categories of the Berlin questionnaire. A positive association between periodontitis and HR-OSA was observed, which showed greater PD and CAL than patients with LR-OSA.

Evidence of treatment efficacy (reversibility)

In addition to evaluating the association, Keller et al. [55] analyzed the prevalence of OSA among periodontal patients. They compared it with the prevalence of OSA among periodontal patients undergoing gingivectomy or periodontal flap surgery. They stated that the prevalence of OSA eased after periodontal therapy, and the results were statistically significant (AOR = 1.36, 95% CI, 1.18, 1.56; P = 0.002), justifying it with a possible reduction in inflammatory contribution, sustained by chronic periodontitis.

1.5.4 Discussion

The primary purpose of this systematic review was to investigate the association between OSA and periodontitis through a qualitative evaluation of the available

literature. These diseases share multiple risk factors, and it has been suggested that both are associated with systemic inflammation and have an impact on the development of hypertension, cardiovascular disease, cerebrovascular disease, and type 2 diabetes [56]. To date, very few studies have been conducted that have assessed the relationship between OSA and periodontitis. Lembo et al. [57] also performed a systematic review to investigate a possible correlation between the two conditions: they concluded that although there is evidence of a plausible association between OSAS and periodontitis, it should be considered as low evidence. The pathophysiological mechanism that could link these two conditions is still unclear, and whether there is a cause-effect relationship or a dose-response relationship is still unclear. Among the articles in the present review, those that demonstrated an association between the two pathologies justified it by formulating different hypotheses: systemic inflammation, oral respiration, and comorbid relationship.

Systemic inflammation

Some studies suggest an inflammatory link between OSA and periodontitis, considering that both diseases present an increase in some inflammation mediator molecules. Hypoxia in patients with OSA would promote an increase in adhesion molecules, C-reactive protein, transcription factor (nuclear factor- κ B), some inflammatory cytokines (interleukin IL-1B, IL-6, and tumor necrosis factor-alpha), and

activation of circulating neutrophils [51,54]. The resulting inflammatory response could then potentiate the disease in those who already suffer from inflammatory diseases (such as cardiovascular, cerebrovascular, pulmonary, and neurocognitive diseases, as well as type 2 diabetes and arthritis) or trigger inflammatory diseases in people with a genetic, behavioral, and environmental predispositions [52,53]. Increased levels of pro-inflammatory mediators and C-reactive protein have also been observed in patients with periodontitis [50]. In periodontitis, the host's response to periodontal pathogenic microorganisms causes an increase in systemic inflammatory factors and the destruction of the integrity of periodontal tissues [58,59].

Mouth breathing

Another factor that may explain the association between the two conditions could be dry mouth due to oral breathing during sleep. In OSA, oral breathing is a classic feature that leads to dry mouth and, therefore, could be indirectly associated with periodontitis through the changes it can cause to the oral environment. In a healthy patient without nasal involvement, mouth breathing accounts for approximately 4% of total ventilation; this percentage tends to increase with aging. In their study, Seo et al. [44] affirm that the prevalence of oral respiration appears to be higher in patients with OSA. By generating dry mouth, this type of breathing tends to decrease saliva's self-cleaning and antibacterial effect. It is, therefore, possible to notice an

increase in bacterial colonization and consequent gingival inflammation. These two factors can increase the risk of developing periodontal disease or trigger its progression.

Comorbidity

Finally, a possible comorbid relationship between the two conditions has emerged from the literature. OSA and periodontitis have several common risk factors, such as tobacco use, male sex, aging, alcohol consumption, obesity, and diabetes, which increase the vulnerability of the development of the two diseases. The simultaneous presence of periodontitis and OSA in an individual would, therefore, be attributable to common risk factors that would link to comorbidities, in contrast to the first two hypotheses in which there is a causal link. It should also be noted that periodontitis is a common disease that affects up to 43% of the general population [30]. According to a study by Heinzer [25], OSA would reach 10%–50% of the general population. It is, therefore, presumable that these two conditions can coexist in the same individual without causing a link between them.

Limitations

Considering that the findings summarized in this systematic review present some limitations is necessary. Although most studies indicated a statistically significant association between periodontitis and OSA, the results need to be interpreted with caution because of the low quality of evidence in many studies. First, most of the included studies had a cross-sectional design, and therefore, it is impossible to identify a causality or directionality between OSA and periodontal disease. The diversity and limited number of studies did not allow for a convincing level of evidence or quantitative analyses to be performed.

One-third of the studies were found to be of poor quality, mainly due to the lack of calibration of the periodontal examiners, the lack of sample size estimation, and the absence of control for potential confounders. The remaining studies were classified as having a moderate-to-low risk of bias. Three [52,53] of the four high-risk-bias studies were conducted by the same authors based on the same sample. They had limitations such as the small number of subjects ($n = 52$) and the absence of subgroups based on periodontal disease status (healthy, gingivitis, or periodontitis). Their results should be, therefore, interpreted with caution.

The assessment of periodontal disease and the definitions used differed between studies; this may have led to an over- or underestimation of the disease prevalence. Despite the calibrated classification of periodontal disease, the case-control division

uses several measures the operator can influence. Measuring the level of plaque, bleeding, mobility, furcation defect, and attachment loss by different operators using different techniques can create some variability and a margin of error. In addition, some studies are limited to a partial periodontal assessment of the mouth compared to others with six measurement points for each tooth. By being aware of the initial assumptions, the examiner's objectivity can be subject to bias during periodontal data collection, hence the need for a blinded approach. Similarly, the AHI cutoffs for OSA assessment varied between studies.

Concurrent control subjects were not used in the two studies. Instead, their results were compared to historical controls from data published in the Australian National Survey of Adult Oral Health [51] and the Longitudinal Health Insurance Database 2000 [55]. CAL is a measure of past disease and not necessarily current disease; therefore, the time between exposure and illness cannot be confirmed. Study case selection can be done using databases of patients who responded positively to questionnaires or by clinical examination. An individualized and standardized approach should be more accurate for diagnosing periodontitis and OSA.

The results may have been influenced since the included studies came from different regions, and demographic and social factors influence periodontal prevalence and severity. Another probable limitation is found in studies that have not distinguished smokers from nonsmokers. Smoking affects not only the increased levels of salivary

cytokines but also the risk of OSA and periodontitis. Likewise, the possibility of having control group members with undiagnosed asymptomatic OSA or other sleep disorders (e.g., snoring) can lead to a lack of uniformity in control groups.

In general, OSA is also more likely to be diagnosed in a patient being treated for periodontitis than in a person unaware of having the condition. This could increase the correlation rate again. None of the studies were wholly corrected for known confounders. The standardization of study groups according to each of these categories is therefore necessary to improve the internal validity of the studies.

1.6.4 Conclusions

This review highlights some evidence of a plausible association between periodontitis and OSA. Several theories have been hypothesized to explain a link between the two conditions: (1) periodontitis causes chronic inflammatory responses in sensitive hosts and acts as a mediator of inflammation for OSA or vice versa; (2) oral breathing associated with OSA increases the expression of periodontitis; and (3) the relationship between the two conditions is comorbid rather than causal as they both share common risk factors.

No conclusions can be drawn about the efficacy of periodontal disease treatment modalities due to insufficient evidence. Future research should, therefore, provide

evidence from observational prospective studies trying to overcome the limitations currently found in the literature. Furthermore, as most papers had a cross-sectional design, it was impossible to define the cause-effect relationship clearly. Therefore, better-structured observational studies are needed to confirm this association, and randomized controlled studies are required to clarify the interaction mechanism between the two conditions.

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Chapter II

Emergence Profile Creation with CAD Technology on Vertical Edgeless Preparation (VEP)

INTRODUCTION

Digital technology is a consolidated reality within dental laboratories, where scanners and CAD/CAM methods have revolutionized design and production processes, combining traditional and innovative techniques and materials. It should be emphasized that the results obtained with these current digital procedures cannot disregard the knowledge of the rules and principles of traditional dentistry. In prosthodontic processes, the spread of digital technologies revealed new treatment possibilities but also proved to have some operative limitations [1–3]. Simplifying procedures granted by digital technologies can lead to thinking that some steps can be skipped. A clear example includes realizing a complete digital workflow without using physical models and adjusting the margin thickness after milling [2]. Ditching procedures, checking the margin, and other precautions are fundamental in producing a precise and durable dental crown.

This work aims to show how to transfer and adapt traditional procedures and concepts onto a more modern and innovative methodology relying on digital

technologies to create the emergence profile of a crown prepared according to the Vertical Edgeless Preparation (VEP) technique [4,5].

This article also illustrates the complete digital workflow of a prosthetic project, from the impressions with an intraoral scanner (IoS) to the creation of a three-element fixed partial prosthesis for teeth prepared according to the VEP technique.

Different techniques for preparing complete dental crowns exist in prosthodontics, each with its characteristics, indications, advantages, and disadvantages. Complete crown preparations have been classified into vertical and horizontal preparations [6].

However, the authors have also subdivided preparation techniques into two groups: the first one includes preparations that present, at their apical part, a defined margin [7]; the second consists of the Vertical Edgeless Preparation (VEP) [4,5], and the intraoperative prosthetic preparation, which both lack a defined margin [8].

Vertical Edgeless Preparation is the technique to which the feather edge preparation technique of the Porta Mascarella School in Bologna has been renamed. It consists of a prosthetic preparation for complete crowns, recommended for dental elements with a loss of periodontal support, and it is performed by extending the preparation under the gingival margin to let the bur condition every part of the root surface, which lost periodontal attachment. This preparation technique does not generate a finishing line but ends in a “finishing area” where the prosthetic margin can be positioned at different levels, ensuring an excellent marginal closure. The absence of steps, edges, or undercuts is the reason for the name “edgeless”. The presence of a transition angle

between the prepared part of the root and the apical portion is unavoidable. Still, this angle will be entirely covered by the regrowth of the soft tissues that were involuntarily but inevitably injured during the preparation process. Therefore, from a clinical perspective, its presence is irrelevant: this defines the “periodontal dominance” of the technique. The position of the final prosthetic margin can then be decided considering the thickness of the tissues, the materials used, and the aesthetic needs of the area and the patient.

This not-bur-shaped technique finds its main indication in teeth with a medium/thick periodontal phenotype and a loss of periodontal attachment, which, as is well known, is not a synonym of active periodontitis. Preparing the exposed part of the dental root removes the section of dental tissue potentially contaminated by toxins and bacteria and protects it from the oral environment. Provisional crowns on VEP-prepared teeth need to be left short on the margin to let the soft tissues heal and mature without obstacles, which could lead to tissue inflammation [4,5].

TECHNIQUE

- Prepare the abutment according to the VEP technique.
- Reline, finish, polish, and deliver the provisional crown, following the VEP technique principles and the traditional prosthodontics concepts. The accuracy of occlusal contacts, lateral and anterior guidance, and interproximal contact points is checked.
- After the complete healing of soft tissues, impressions are ready to be taken. Firstly,

take the digital impression of the arch with the provisional in place.

- Then, take a definitive digital impression. The double retraction cord technique is recommended to obtain a complete and clean impression of the gingival sulcus.

Mattifying powder can also help avoid light reflections from the teeth surfaces.

- Take the impression of the opposite arch and the vestibular impression in maximum intercuspation position.

- Send the obtained files to the dental lab.

- The dental technician digitally draws the margin of the crown in the most apical visible

part of the sulcus, creates the internal spacing, and uses the provisional crown shape as a starting point for the digital wax-up.

- The technician performs a digital cutback, leaving 1 mm of space on the surfaces needing layering but keeping the intrasulcular part intact.

- The resulting frame is tested on the abutment to check the accuracy of the seating and the position of the prosthetic margin, which can be shortened and arranged less apically in the sulcus. The emergence profile and its angle can be modified depending on the relationship between the abutment surface and the gingival margin, in case the gingival zenith needs to be altered or the soft tissues need more support from the prosthetic crown.

- A 3D abutment model is printed with high precision, and the ditching procedure is performed. This lets the dental technician check the emergence profile after designing it digitally.
- The ceramic layering phase is performed on the 3D-printed full-mouth model obtained from the STL files.
- The crown margin thickness must be reduced to the minimum during the finishing procedure and then polished with diamond rubbers. Intraoral checks for shape, occlusal, and interproximal contact points are performed. The congruity of the color is confirmed. The emergence profile and the depth of the crown margin within the sulcus are also verified and potentially modified.
- The prosthetic crown is ready to be delivered following the cementation protocol of the chosen material

Clinical Case

2.1 Preparation and Impressions

A fixed partial prosthesis (FPP) is taken as an example of this technique.

A 51-year-old man came to the clinic with an old metal–ceramic FPP in the aesthetic area, whose margins were visible and whose aesthetic appearance was insufficient. The old FPP from 1.2 to 2.1 was removed and replaced with a new FPP made of zirconia and ceramic (Figure 1). Once the old FPP was removed, the underlying abutments were prepared according to the VEP technique (Figure 2, Figure 3, and

Figure 4), and a metal–resin provisional FPP was adapted, relined, finished, and luted (Figure 5). The provisional FPP was designed to avoid altering the patient’s maximum intercuspation position. Subsequently, the accuracy of the occlusal contacts was checked, and the protrusive and lateral guidances were functionalized.



Figure 1. The abutments as they were found under the old FPP

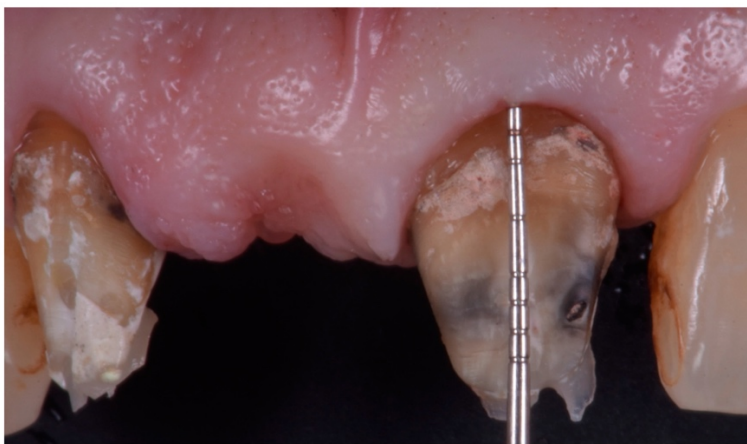


Figure 2. The periodontal mapping is performed according to the VEP protocols

The margins of the provisional FPP were placed at an iuxta-gingival level so that they would not interfere with the healing process of soft tissues, which were slightly but necessarily injured during the subgingival preparation procedure.



Figure 3. The bur is used according to the periodontal mapping



Figure 4. The abutments prepared according to the VEP technique

Precise impressions represent the way clinicians communicate the information of the clinical case to the dental laboratory and through which the prosthetic work is

realized. Numerous preliminary conditions need to be satisfied before taking a correct impression of intraoral structures.



Figure 5. Provisional FPP in place

An adequate prosthetic treatment requires the correct sequence of operative procedures and their clean execution. The accuracy in the abutment preparation, a good adaptation of the provisional restoration, and the proper management of soft tissues are crucial points to register the information precisely.

Digital impressions for the definitive FPP were taken four weeks after preparing, waiting for the soft tissues to heal and reach complete stability [9]. As for analogic impressions, given the type of preparation, the double cord technique was used in this case. Specifically, a silk cord 2-0 and a second silk cord 0 (Ultrapack, Ultradent Products, Inc., South Jordan, UT, USA), soaked in a 25% aluminum chloride (Racestypine, Septodont, Saint-Maur-des-Fossés, France) solution, were used. Both

cords were inserted without trauma to guarantee the displacement of the soft tissues both horizontally and vertically, allowing a better scan of the prepared dental tissues placed under the gingival margin. The digital impression was taken using the intraoral scanner Omnicam (Dentsply Sirona, Charlotte, NC, USA). Before starting with the scan, the second cord (the outermost of the two) was gently removed. A thin layer of mattifying powder (Apollo DI Speedspray, Dentsply Sirona, Charlotte, NC, USA) was applied to the teeth and the soft tissues. According to the authors' experience, powder guarantees a more straightforward and smoother procedure and a better intrasulcular impression (Figure 6).



Figure 6. The powder is used to take IoS impressions to obtain a more predictable result

The STL files obtained from the impression were finally sent to the dental laboratory. The dental laboratory receives the STL files of the upper arch with the prepared abutments, the lower arch, their relationship in maximum intercuspation, and the

upper arch with the provisionals in place. Then, the files are imported into the CAD software (Exocad 3.1, Exocad GmbH, Darmstadt, Germany), and the margin of the prosthetic crown, below the gingival margin, is determined. Generally, this point matches the most apical visible part of the prepared surface (Figure 7). The prosthetic axis is now defined, checking the absence of undercuts and disparallelisms between the abutments (Figure 8).

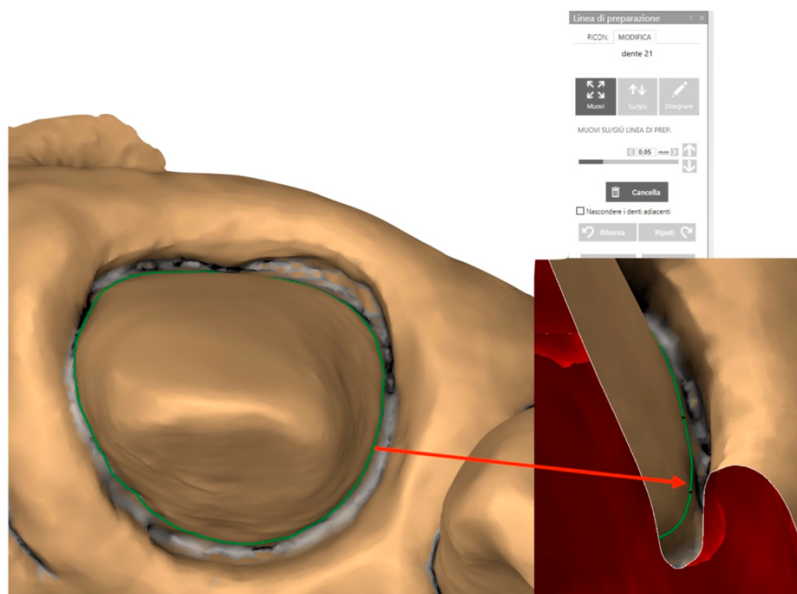


Figure 7. The margin of the prosthetic crown is digitally placed at the most apical visible position

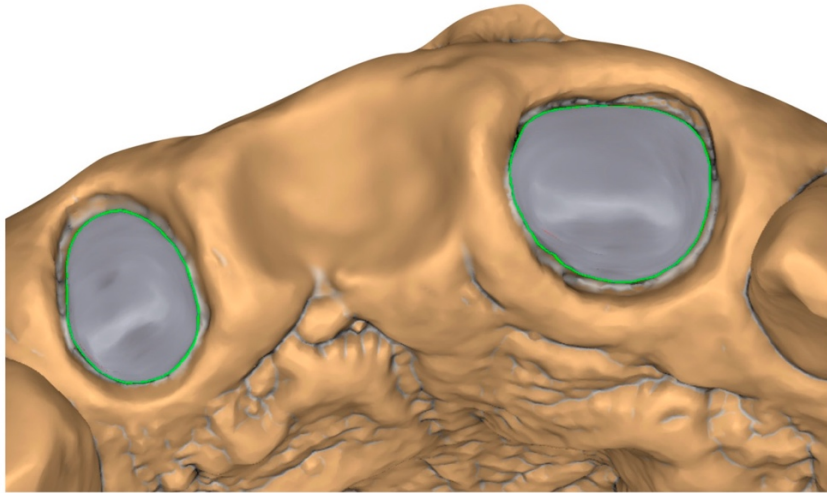


Figure 8. Definition of the insertion axis: the absence of disparallelism and undercuts are checked

Subsequently, the software creates the internal spacing of the crown according to the length and width of the abutment and the material chosen for the prosthetic restoration. Virtual models are now articulated to check the accuracy of maximum intercuspation (Figure 9). At the same time, upper and lower models are obtained with 3D printing and are used only as control models. The impression of the prepared abutments and the provisionals are superimposed to verify the correspondence of articulation relationships (Figure 10).

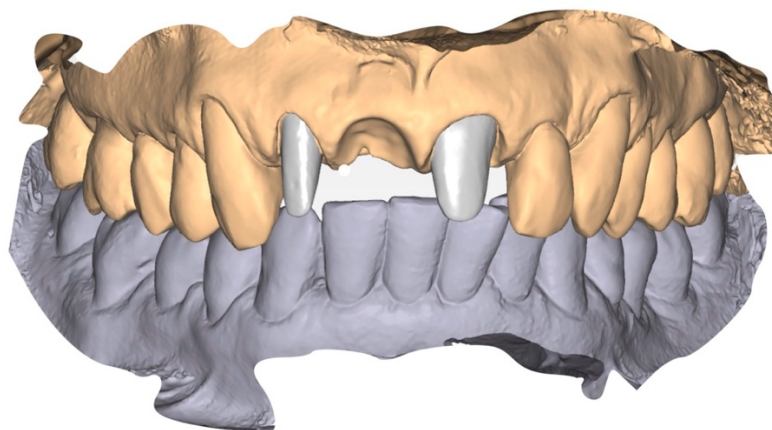


Figure 9. Internal spacing is defined.

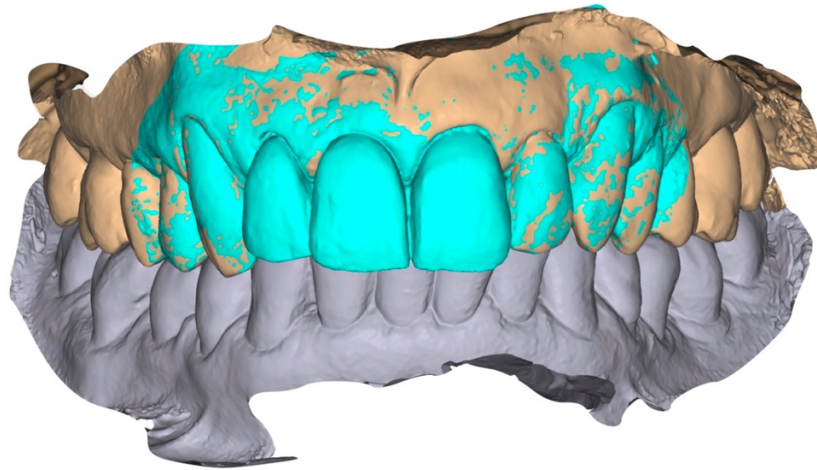


Figure 10. Impression with the provisional FPP

This procedure, which uses the information obtained from the provisionals, allows the technician to improve and speed up the final wax-up design (Figure 11a). The virtual cutback is performed once the project is finished (Figure 11b). As for analogic techniques, this allows the generation of a frame whose morphologic features guarantee adequate resistance and an optimal and homogeneous thickness for the layering ceramic. The cut-back reduction consists of 1 mm on all the surfaces on which ceramic layering is necessary.

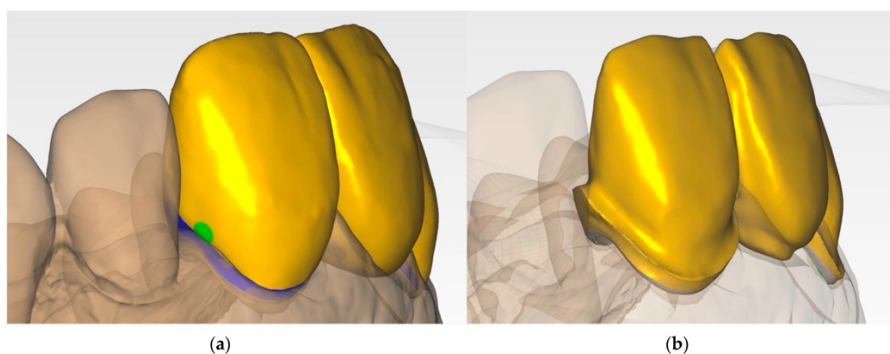


Figure 11. (a) Digital wax-up and (b) digital cut-back.

2.2 Digital Creation of the Emergence Profile

The intrasulcular part of the crown is left intact (Figure 12a). This allows for maintaining a margin whose properties are effective in enduring the working process and, subsequently, the load of masticatory function [6]. The prosthetic margin has a triangular form, and its dimension is determined by the area between the surface of the abutment and the gingival sulcus, which plays a crucial role in defining the anatomy of the emergency profile [10]. It is possible to modify the prosthetic margin if there is a need for corrections. It is also possible to increase or decrease the angle of the emergency profile if the harmonization of the gingival zenith is desired or if more support of soft tissues is needed (Figure 12b).

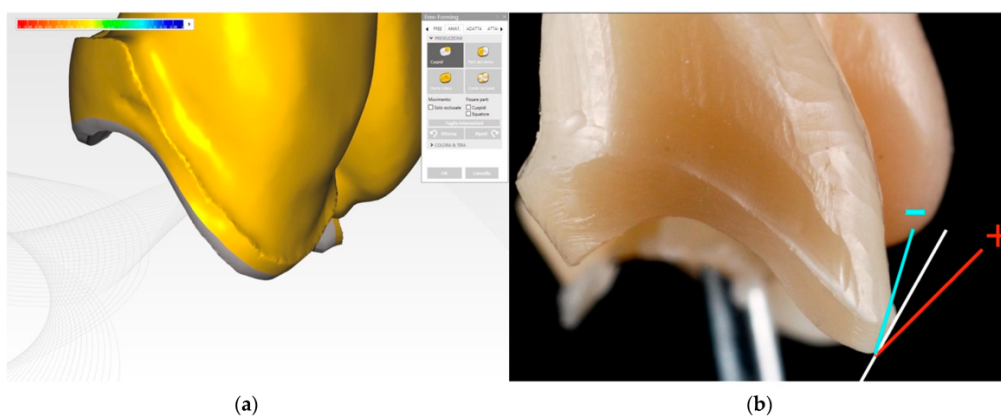


Figure 12. Intrasulcular part of the crown. (a) Digital and (b) milled

During the phase of ceramic layering, the angle of the emergency profile helps to maintain the whole crown profile as defined by the digital design. The zirconia frame project is now ready and can be milled. The multilayered zirconia (in this case, Katana UTML, Kuraray, Chiyoda, Japan) frame is milled from a disk and then sintered in a furnace (in this case, Multimat 2sinter, Dentsply Sirona, Charlotte, NC, USA) at 1500 °C, according to the indications given by the producer (Figure 13).



Figure 13. Zirconia frame

After sinterization, a first check is performed using the model obtained through 3D printing. The model accuracy, however, is not so high, and it is necessary to check the frame directly in the patient's mouth. The model is used mainly as a support in the subsequent layering phases. The frame is then checked directly on the abutments, and a series of verification procedures are performed. First, the insertion axis is checked to verify that there are no undercuts on the prepared abutment along the insertion axis. Then, when dealing with a partial fixed prosthesis, as in the case used

as an example in this article, it is necessary to check that the intermediate element guarantees the correct compression on the soft tissue and that there is no tilting. Verifying that the correct seating and frame precision is performed using the same procedure as the analogic workflow. A silicon paste (Fit Checker Advanced Blue, GC Corporation, Tokyo, Japan) is used to detect and eventually correct major defects (Figure 14a). Subsequently, to perform a more accurate check, a paste with zinc oxide and eugenol (Impression Paste Kit SS White, SS White Dental Group, Lakewood, NJ, USA) is used (Figure 14b). In this phase, the frame's retention on the abutment is also evaluated.



Figure 14. Correct seating and frame precision are checked with (a) silicon paste and (b) paste with zinc oxide and eugenol

During the seating verification procedures for the frame, it is possible to check the prosthetic margin in its extension, thickness, and axis. Any overextension that may interfere with the periodontal tissues can be modified and corrected. Moreover,

reducing intrasulcular extension during subsequent laboratory procedures is possible if the clinician considers it necessary.

The margin thickness, measuring 0.15–0.2 mm, must be reduced to the minimum during the finishing procedures and then polished with diamond rubbers (Figure 15a).

The ceramic layer is then placed so that it follows the emergence profile smoothly (Figure 15b).

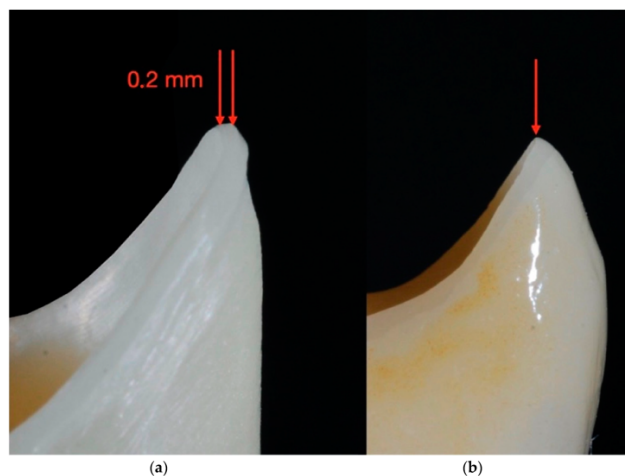


Figure 15. Intrasulcular component of the frame without (a) and with (b) the ceramic layer

In the case shown as an example, given the high aesthetic value of the work, the ceramization of the zirconia frame is performed directly in the dental office while the patient is present (Figure 16). Before finishing this phase, the prosthesis undergoes another series of checks. First, the insertion axis is verified again, together with the suitability of the interproximal contact point. The evaluation of the emergence profile and the accessibility of the interproximal zone for hygienic maneuvers is performed.



Figure 16. Final result

Now that the frame is layered with ceramic, the occlusal contact points are verified first with a thin articulation paper and then with a Shimstock foil (Dental Medical, Maribor, Slovenia), which, thanks to its 8 μm thickness, allows the clinician to reach great precision. Considering that the example shown in this article involves an anterior FPP, the assessment of the incisor guidance is performed. Finally, the aesthetic and phonetic analysis is performed.

DISCUSSION

Vertical Edgeless Preparation (VEP) does not present a finishing line but ends in a prosthetically usable area whose extension may vary according to the depth of the periodontal sulcus. For this reason, the position of the prosthetic margin is not conditioned by finishing lines, steps, transition angles, and relative undercuts. Its

position can instead be chosen based on different factors, the first of which is the position of the gingival margin on the abutment [4,5].

Using intraoral scanners to make impressions of abutments prepared with the VEP technique allows for easy detection of zones with defects (preparation/scanning errors), duplication of the provisional emergence profile if necessary, and copying the form, the depth, and the width of the gingival sulcus, which is a fundamental step in the creation of the emergence profile. Moreover, all the elements obtained with a digital impression are measurable, quantifiable, and replicable. However, learning and applying the traditional and fundamental periodontal and prosthetic concepts are crucial to successful rehabilitation. The absence of overcontour, the design of a correct emergence profile, and the right location and strength of the occlusal contact point are crucial aspects to be considered in modern prosthodontics since materials may have changed over the years, but biology and biomechanics have not. Using an entire digital procedure may often lead to skipping essential steps in finalizing a dental crown. The fact that no physical model is produced makes it challenging to perform the verification procedure, especially when the tooth has been prepared with a vertical preparation technique [2]. Indeed, the impossibility of fulfilling the ditching procedure and the lack of control over the emergence profile can lead to huge imprecisions. Instead, this technique controls the emergence profile during the CAD procedure, on the 3D printed abutment model, and on the prepared abutment. Thanks to these steps, a perfect check of the emergence profile and a very thin

thickness of the crown margin can be obtained. Moreover, this technique freely allows for determining how deep the crown margin goes in the gingival sulcus and modifying it according to the patient's aesthetic needs and the gingival profile.

The precision of intraoral scanners has made significant progress in recent years, and the literature on the topic is not unanimous in defining a degree of accuracy compared to the traditional impression [11]. However, in vitro studies have shown that the marginal and internal fit of crowns and FDP obtained from digital impressions are more precise than the ones obtained from traditional impressions [12,13].

Choosing the correct material to use also requires a careful evaluation based on the literature and the clinician's expertise [14]. Understanding and applying traditional techniques and procedures is fundamental to designing full crowns with digital tools. These digitally manufactured crowns must fulfill precision, function, and aesthetic needs exactly as analogically manufactured ones. It is essential to underline that the correct use of digital procedures requires specific skills and training both for the clinician and the dental technician.

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Chapter III

Post-preparation temporary crowns manufacturing on teeth prepared with VEP: a digital protocol

INTRODUCTION

Provisional restoration is defined as a restoration that provides protection, stability, and function before the fabrication of a final prosthesis, being used to establish the aesthetics, function, and therapeutic efficacy of a treatment plan [1].

The provisional prosthesis plays a central role in prosthetic treatment; it represents a faithful reproduction of the wax-up of the initial prosthetic design and, once placed in the mouth, allows the patient to be in a state of functional and aesthetic comfort throughout the treatment period. The temporary should be constructed of easily modifiable materials with stability, reliability, and ease of handling characteristics such that they effectively resist the chewing forces and degradation associated with exposure to the oral environment. Temporaries used in fixed prosthetics are divided into pre-preparation and post-preparation.

The pre-preparation temporary crown is made in the laboratory, starting with the design wax-up before the clinician prepares the prosthetic abutments. Once the

prosthetic abutments have been prepared, the pre-preparation provisional will be seated in the mouth, relined, finished, and cemented.

The post-preparation provisional crown is made in the laboratory using the model obtained from the precision impressions of the prosthetic abutment preparations.

The use of a post-preparation provisional is indicated when the complexity of the prosthetic treatment implies that the pre-preparation provisional does not guarantee the aesthetic and functional changes programmed in the definition of the treatment plan.

Digital technology is now an established reality within dental practices. The digital workflow involves the use of intra-oral scanners (IOS) to take impressions [2-4] and CAD/CAM methods that allow the production of temporary crowns directly in the dental office [5], with both traditional and innovative materials. This paper will illustrate the all-digital workflow for the fabrication of immediate post-preparation temporary crowns, starting from an impression with IOS up to the fabrication of a temporary crown on a central incisor prepared using the Vertical Edgeless Preparation (VEP) technique [6-8]. The described method aims to demonstrate how gingival placement of the prosthetic margin of the provisional crown is done using design software. Although the preparation extends deeper into the sulcus, it allows undisturbed healing of the gingival tissue [9].

The immediate chairside post-preparation provisional crown, produced with digital flow, has the clinical ability to repeat the characteristics of marginal accuracy,

function, aesthetics, and biological integration required for this type of prosthetic restoration.

TECHNIQUE

The original method is described through the presentation of a clinical case in which the treatment plan involved the rehabilitation of a left upper central incisor with prosthetic crown failure following a complicated coronal fracture, with significant loss of tooth substance and absence of ferrule (Fig. 1).



Figure 1. Prosthetic crown failure following complicated coronal fracture on the upper left central incisor

The treatment plan included preliminary reconstruction of the fractured tooth using a fiber and composite post, preparation of the prosthetic abutment using the VEP technique (Fig. 2, 3), application of a chairside immediate post-preparation

provisional crown, and definitive prosthetic rehabilitation with a single zirconia crown layered with feldspathic ceramic.



Figure 2. Frontal view of the prosthetic abutment prepared by VEP technique



Figure 3. Occlusal view of the prosthetic abutment prepared by the VEP technique

VEP [3-5] is a full-crown prosthetic preparation indicated for dental elements that have lost periodontal support, even minimally, although it is also effective at physiological probing depths (≤ 3 mm). The technique involves extending the

preparation below the gingival margin to prepare the entire root wall surface free of attachment. The preparation does not hesitate in a finish line and its transition angle but instead ends in a “finish preparation area” in which the prosthetic margin can be placed at different height levels while maintaining a reliable closure.

At the end of the preparation, a digital impression of the prepared abutment, antagonist arch, and articulation relationships was immediately taken using the intraoral scanner. The STL files obtained must then be uploaded to the design software (CAD software).

The workflow on the CAD software initially involves defining the position of the prosthetic margin of the provisional crown, which must be identified at the gingival margin level, even if the preparation extends deeper into the sulcus (Fig. 4-6).

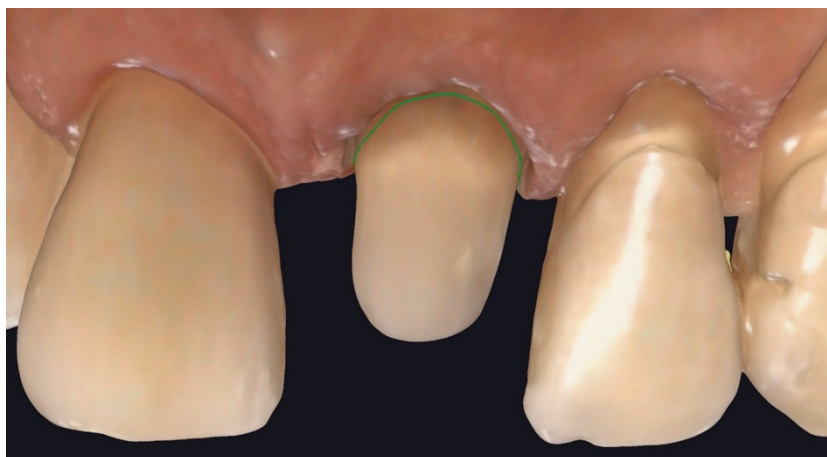


Figure 4. Vestibular view of the prosthetic margin design on the CAD software

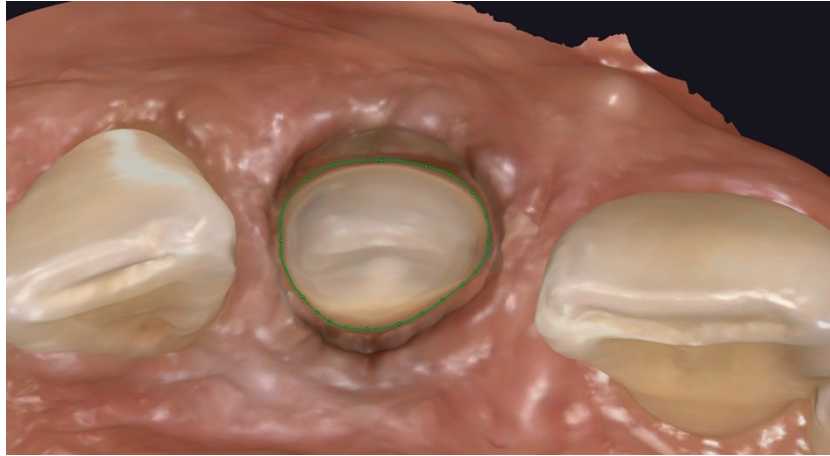


Figure 5. Occlusal view of the prosthetic margin design on the CAD software

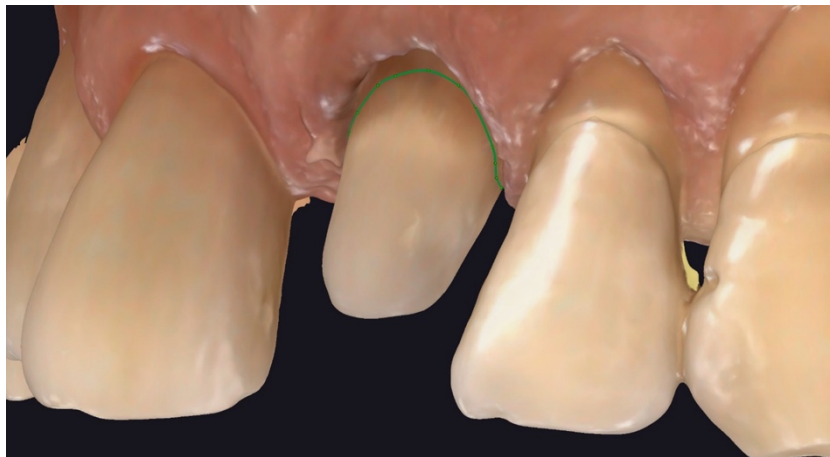


Figure 6. Lateral view of the prosthetic margin design on the CAD software

At the end of preparation with the VEP technique, a parietal transition angle will inevitably form on the most apical section of the prepared tooth surface, resulting from the convergence between the prepared and unprepared wall. The prosthetic margin will be positioned more coronal to this transition angle so that the gingival tissues, inevitably injured by the drill, can heal without interference related to the presence of the temporary crown or any residual subgingival cement. The provisional is, therefore, placed “short” in relation to the extent of the prepared tooth area. This

allows the undisturbed healing of the gingival tissue, with the formation of an epithelial attachment that will completely cover the transition angle resulting from the convergence between the prepared and unprepared wall. The CAD software then requires the definition of the prosthetic insertion axis, that verification of the absence of undercuts in the prosthetic abutments and the determination of the correct emergence profile of the prosthetic construct (Fig. 7, 8).

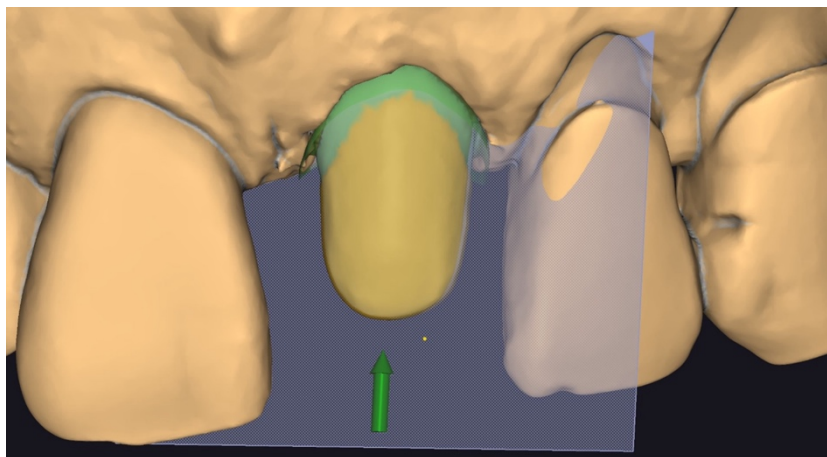


Figure 7. Prosthetic design on CAD software: the green arrow indicates the insertion axis of the prosthetic artifact, while the green area located at the gingival margin level defines its emergence profile

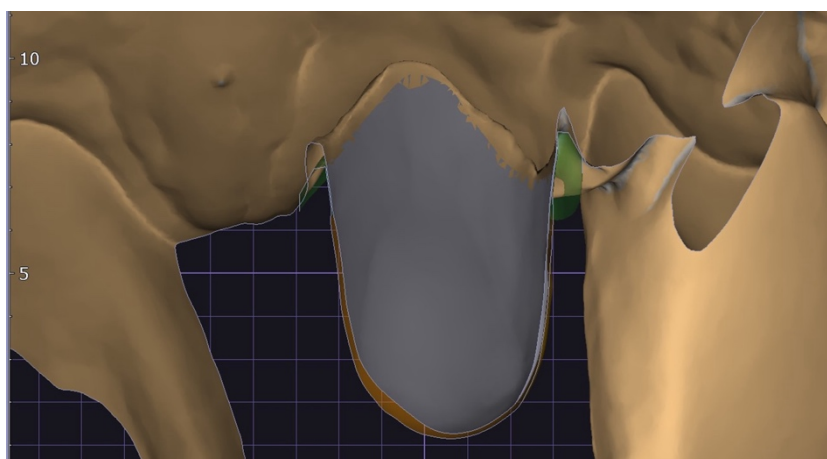


Figure 8. Emergency profile section of the provisional crown

Consequently, it allows to create digitally, according to the set parameters, the internal spacing of the crown, which will vary according to the length and width of the

abutment, the material chosen for the prosthetic artifact, and the inclination of the preparation walls.

For the definition of the tooth shape, the CAD software allows copying the shape of the contralateral so that it can integrate harmoniously with the patient's teeth and smile. Once this step is completed, the software generates a proposed prosthetic artifact on which any changes inherent in shape, contact points, and occlusal contacts can be made (Fig. 9, 10).

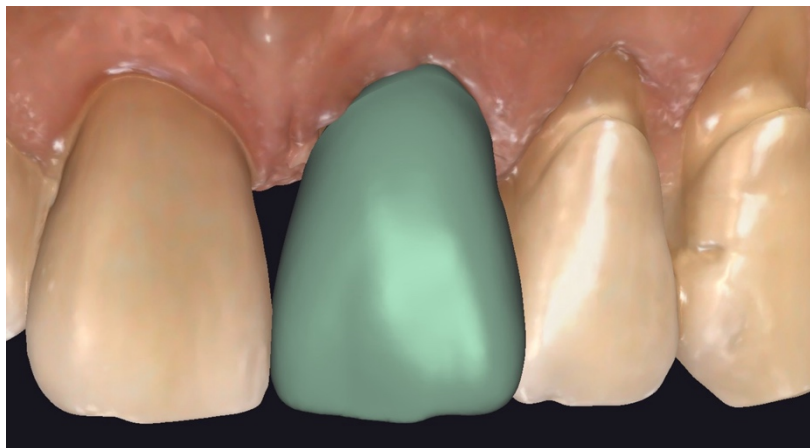


Figure 9. Provisional shape design on CAD software

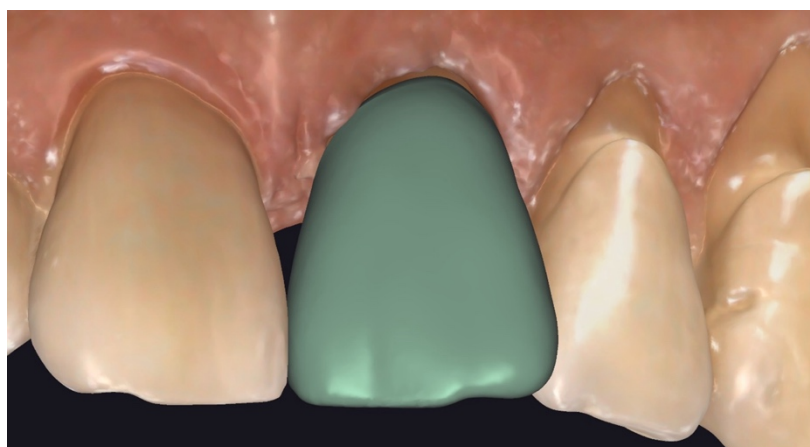


Figure 10. Buccal-incisal tilted view of the provisional crown design in which the gap between the apical portion of the preparation and the prosthetic margin can be observed

The resulting virtual models are then articulated with each other to verify that the references of the maximum intercuspation are correct.

Once the digital design of the provisional single crown is completed, the STL file obtained must be sent to the milling machine.

The post-preparation provisional crown is milled using a provisional resin. Next, the obtained provisional crown must be finished, polished, and characterized since it is highly aesthetic and blends in perfectly with the patient's smile (Fig. 11).



Figure 11. Frontal view of the cemented temporary crown

After 4 weeks, healing of the periodontal tissues around the provisional crown appears optimal (Fig. 12-14), and the precision impression of the prosthetic abutment can then be taken with IOS for fabrication of the final zirconia crown layered in the buccal area with feldspathic ceramic.



Figure 12. Frontal view of the temporary crown after gingival tissue healing



Figure 13. Frontal view of the abutment following removal of the temporary crown



Figure 14. Occlusal view of the abutment following removal of the temporary crown

DISCUSSION

Digital technology allows the fabrication of immediate post-preparation provisional crowns chairside. Once the prosthetic abutment is prepared, digital technology allows the impression to be taken with IOS, the prosthetic device to be designed using software, and the designed crown to be milled directly in the office.

This paper describes the fabrication of a temporary crown in the aesthetic zone.

The original method presented makes it possible to reduce the number of sessions since there is no need to take a preliminary impression to be sent to the laboratory to construct the pre-preparation provisional crown. CAD software makes it possible to define the ideal finishing line of the prosthetic margin and the emergence profile of the provisional crown, ensuring the healing of the gingival tissues. The provisional crown made with this digital workflow provides better accuracy, function, aesthetics, and biological integration characteristics than a pre-preparation temporary crown relined directly in the mouth. The milled temporary crown has smooth, highly polished walls, even at the finishing margin. This aspect makes it more integrable with periodontal tissues than relined temporary crowns that retain residual porosity at the margin related to the nature of the resin.

Digital design software allows the anatomy of the provisional crown to be customized to the patient, allowing the operator to copy the anatomy of adjacent or contralateral teeth or even create a new anatomy from preloaded libraries.

In addition, using CAD software facilitates the management of occlusion, as it automatically defines occlusal contacts, with a desirable decrease in occlusal modifications to be performed directly on the patient and a consequent reduction in the margin of error and operative time.

Digital technologies initially require a high cost to purchase equipment and software and, subsequently, a learning period. In addition, the digital workflow described is not yet applicable to cases of extensive rehabilitation, so it has limitations in terms of treatment plan selection.

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Chapter IV

Accuracy of different 3D printers in the fabrication of digital dental models and adhesive indirect restorations: a micro-computed tomography analysis

INTRODUCTION

Three-dimensional printing is an additive manufacturing procedure that utilizes computer-aided design (CAD) to produce complex 3D constructs with desired geometries, allowing for a highly efficient, low-cost, and patient-specific design approach with the potential for rapid prototyping [1]. Nowadays, a wide range of dental treatment trials, including orthodontics, dental implants, mandibular reconstructions, prosthodontic rehabilitation, surgical, and nonsurgical endodontics, have extensively exploited 3D printing technology [2]. In particular, 3D printers are becoming increasingly popular in prosthodontic because they can produce a wide range of lower-cost dental prostheses in a short time, using a variety of materials including zirconia [3], titanium [4] and polymer-based resins [5]. In addition to

improving patient care, 3D printing can also be more efficient and cost-effective than traditional manufacturing techniques, as it allows for the production of complex and customized products on demand, without the need for large quantities of inventory or specialized equipment. 3D printers can also be used in combination with conventional methods to produce indirect restorations, crowns and bridges in dental laboratories. For example, additive manufacturing can be used to create polymeric wax models for casting metal restorations or to press restorations from pressable materials such as lithium disilicate (LD) [6]. There are two distinct methods available to produce LD restorations. One technique is based on high vacuum injection, where ceramic ingots are hot-pressed (press) in a mold where a waxed crown was invested. However, a more controlled process can be achieved by replacing the conventional waxed restoration with 3D printing [7]. In fact, conventional wax pattern fabrication is a technique-sensitive and time-consuming process, and the quality of the final product depends on the skill of technician. In addition, intrinsic features of wax such as thermal sensitivity, elastic memory, texture, and high coefficient of thermal expansion limit its use [8]. Dental printers are also more affordable than milling machines and result in a less production material waste. A few studies analyzed wax patterns produced using a 3D printer and compared them with those produced using digital subtractive manufacturing or traditional methods. The results showed little discrepancy between the various methods, concluding that 3D printers can be a valid substitute in the production of indirectly pressed restorations [9-11].

It must also be considered that the longevity of indirect restoration, whether from a mechanical or a biological standpoint, is directly associated with the quality of marginal and internal fit [12-15]. Significant marginal discrepancies result in the dissolution of the luting agent and favor the microleakage of bacteria and their byproducts. Consequently, the tooth becomes more susceptible to inflammation of the vital pulp (post-operative sensitivity), secondary caries, and marginal discoloration [18-23].

Some studies have shown that resin cement performance can be optimized when the internal gap of restoration is 50–100 μm , and bonding benefits were lost at thickness approaching 450–500 μm due to polymerization shrinkage stresses [24-27].

With the introduction of 3D printers as a production method for indirect restorations emerges the requirement to evaluate their marginal and internal fit to understand whether new technologies can replace traditional production methods.

Several studies in the literature have compared the accuracy of LD indirect restorations fabricated using 3D printing with those produced from milling or traditional workflows, with conflicting results [7, 27-37]. However, only two studies analysed the marginal and internal fit of overlays using a MicroCT, which allows 2D and 3D investigations of the gaps within the range of a few micrometers at multiple sites and directions [7-33], and neither of them analyzed overlay restorations. This study aims to appreciate whether the production of overlays using a 3D printed wax based digital workflow is comparable to the production of overlays using a traditional

workflow in terms of marginal and internal fit and, thus, clinical effectiveness. Additionally, this study aims to evaluate if certain variables such as the production method of dental models, the type of tooth preparation or the printer type may affect the accuracy of LD overlay restorations.

MATERIALS AND METHODS

Two upper-third molars extracted for orthodontic reasons were prosthetically prepared to receive an indirect partial adhesive restoration (overlay) using two different preparation techniques. Sample 1 was prepared with net margins, inclined planes, and no interproximal boxes. Three circular retention grooves were added in the center of the occlusal plate to prevent slippage of the prosthetic restorations once they were in place (Figure 1). Sample 2 was prepared with circumferential beveled margins, interproximal slots, and mesial-to-distal occlusal grooves (Figure 2).

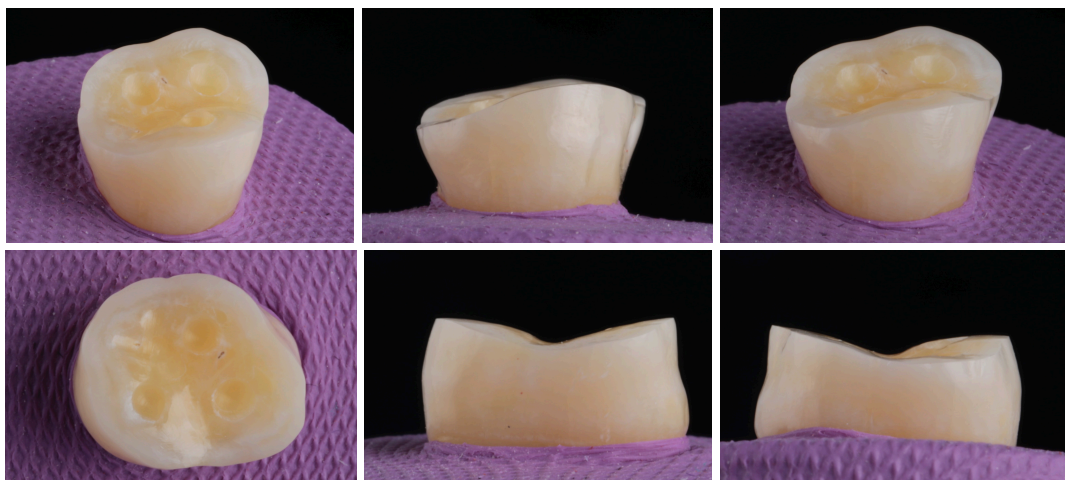


Figure 1. Sample 1 after prosthetic preparation



Figure 2. Sample 2 after prosthetic preparation

Production of dental models

Before preparation, both teeth were ‘pre-scanned’ with an intraoral scanner, taking three digital impressions of each.

After the prosthetic preparation, three impressions were taken with a conventional impression material (polyvinylsiloxane) for each tooth, from which three plaster models were made. Similarly, for each prepared tooth, three digital impressions were taken with an intraoral scanner, and three digital impressions were taken from the pre-preparation scans of the untreated teeth. These were obtained to simulate the clinical practice of scanning the dental arches before tooth preparation and then taking a digital impression covering only the prosthetic preparation area once the tooth has been treated: the pre-preparation scan appears on the scanner order form

and is sent along with the other scans to the lab. A printed resin model was obtained from each digital impression using two 3D printers (Asiga Max, Asiga, Australia; Sinergia Print, Nobil Metal, Denmark).

In total, the following dental models were obtained for each sample:

- Three plaster models (PM)
- Three resin models printed with the Asiga printer (printer A – pA) starting from a digital impression with a pre-preparation scan (pAM-pS)
- Three resin models printed with the Asiga printer starting from a digital impression without a pre-preparation scan (pAM-S)
- Three resin models printed with the Nobil Metal printer (printer B – pB) starting from a digital impression with a pre-preparation scan (pBM-pS)
- Three resin models printed with the Nobil Metal printer starting from a digital impression without a pre-preparation scan (pBM-S)

Production of overlay restorations

Indirect lithium disilicate overlay restorations (Figure 3) were then produced for both prosthetic preparations with different manufacturing techniques.



Figure 3. Lithium disilicate adhesive indirect restorations

For each specimen, the following LD indirect restorations were fabricated:

- Three overlays were produced by traditional technique: traditional impressions, cast models, wax modeling of the artifact and heat-pressing (overlays - O).
- Six overlays produced by CAD-CAM technique with the Asiga 3D printer (printer A overlays – pAO): digital impression with intraoral scanner, digital model, castable wax polymeric patterns 3D printing and heat-pressing. Three overlays were produced from a digital impression of the prepared tooth that without a

pre-preparation scan (pAO-S), three from an impression of the prepared tooth with a pre-prepared impression attached (pAO-pS).

- Six overlays produced by digital technique on Nobil Metal 3D printer printer B overlays – pBO): digital impression with intraoral scanner, digital model, castable wax polymeric patterns 3D printing and heat-pressing. Three overlays were produced from a digital impression of the prepared tooth that without a pre-preparation scan (pBO-S), three from an impression of the prepared tooth with a pre-prepared impression attached (pBO-pS).
- Three overlays were produced by “hybrid technique” with an Asiga 3D printer: the artifact was 3D printed with polymeric castable wax on the Asiga printer (Figure 4), then the finish line was removed and remodeled with wax by the dental technician on the digital model 3D printed by the same printer, then heat-pressed (printer A overlay relined – pAO-R).
- Three overlays produced by “hybrid technique” with Nobil Metal 3D printer: the artifact was 3D printed with polymeric castable wax on the Nobil Metal printer, then the finish line was removed and remodeled with wax by the dental technician on the digital model 3D printed by the same printer, then heat-pressed (printer B overlay relined – pBO-R).

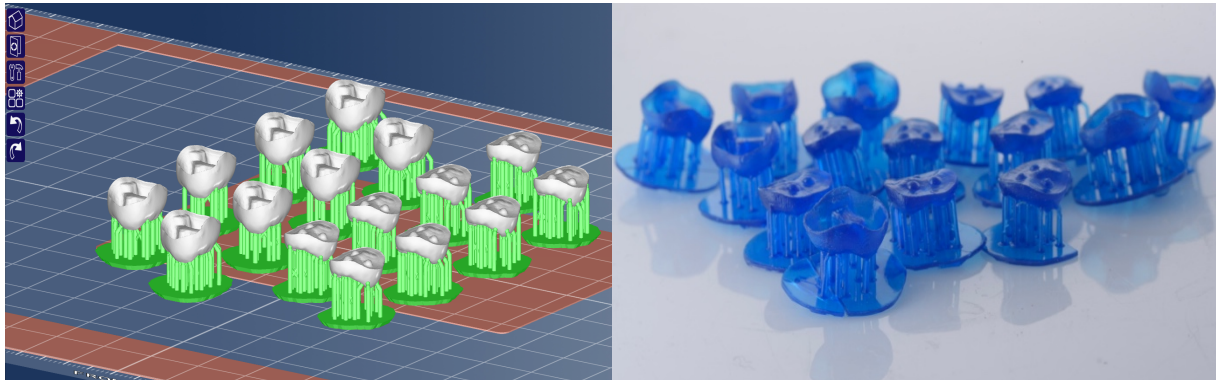


Figure 4. Design and printing of polymeric castable wax overlay artifacts

Micro-CT examination and analysis

All dental models were scanned with Micro-CT (Skyscan 1276, Bruker, Belgium). Imaging was performed at 75-kilovolt peak (kVp), 100 mA, filter Al+Cu (aluminum + copper) with a resolution of 4096x4096 pixels. The pixel size was 7,8 μm , the scanning mode used was step and shot with a rotation angle of 0,2 degrees with average images of 3, and the scan time was approximately 5 hours. All overlays were also subjected to a Micro-CT exam, once placed one at a time directly on samples 1 and 2. To ensure that the overlays remained well positioned on the prepared teeth and did not slip during radiographic examination, they were bonded to the specimens by orthodontic elastics. After the scanner, the images were reconstructed using dedicated software (NRecon; SkyScan).

The images obtained from the 3D radiography reconstructions were then processed and analyzed using SkyScan Dataviewer, SkyScan CTAn, and SkyScan CTvox softwares (SkyScan, Bruker, Belgium). To check the repeatability and degree of error of the model production methods, dental patterns of the same type (e.g., the 3 plaster models) were superimposed, and the discrepancy between replicas from the same workflow was assessed (Figure 5). Then, models of different types were superimposed too to evaluate the discrepancy between patterns produced by different workflows and to assess which was most similar to the natural tooth.

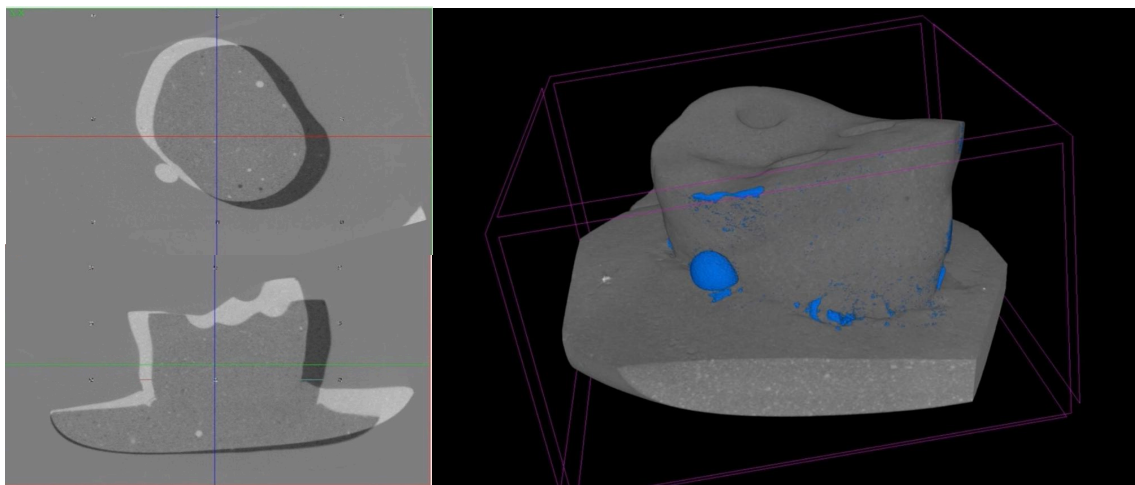


Figure 5. Dental models superimposition

Micro-CT images of the overlays placed on the specimens were analyzed at 360 degrees to evaluate the marginal closure gaps and internal gaps of the adhesive restoration by linear measurements (Figure 6, 7). For each indirect restoration, twenty-eight linear measurements (fourteen for the marginal gaps, fourteen for the

internal gaps) were taken at different points across the overlay-tooth complex to ensure a sample size adequate for the statistical relevance of the study.

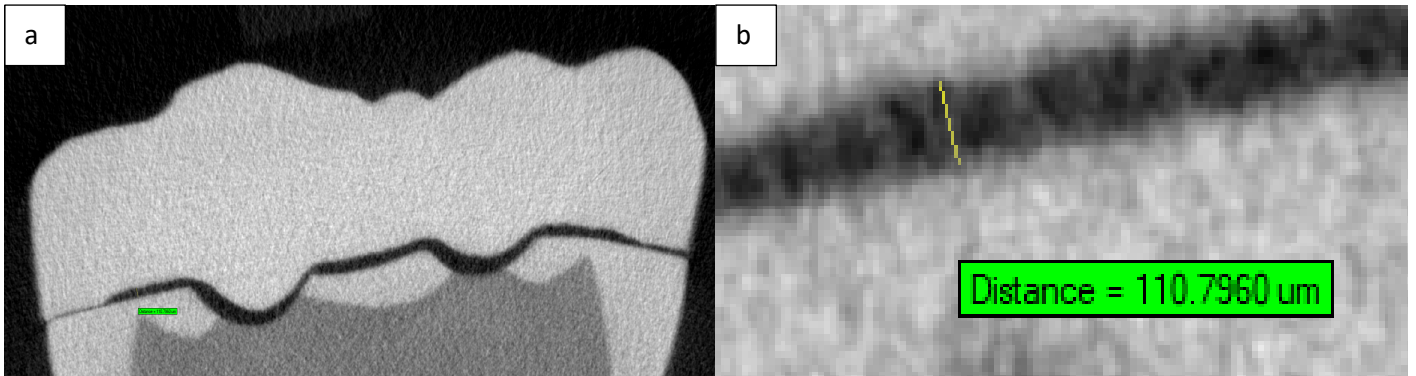


Figure 6. Linear sitting measurement (a). Detail (b).

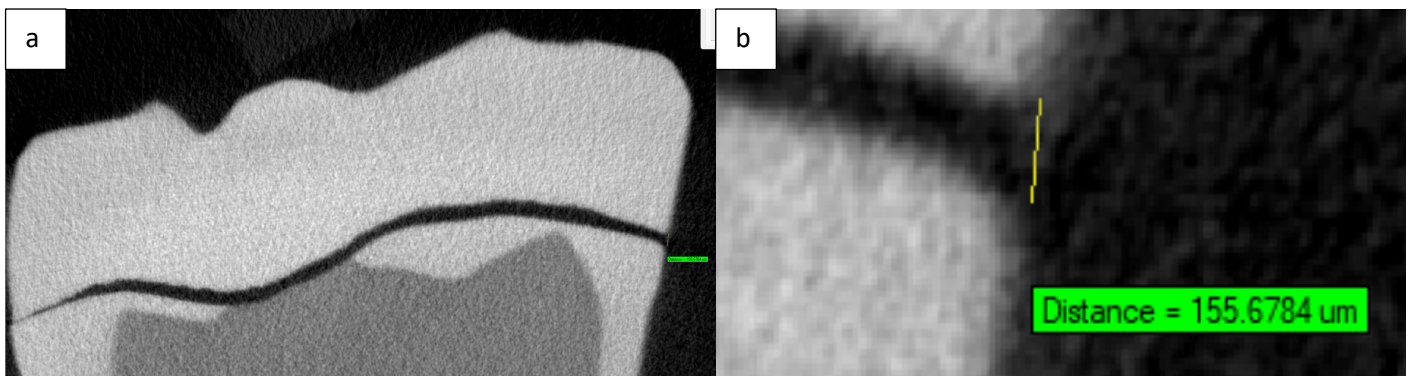


Figure 6. Linear marginal gap measurement (a). Detail (b).

The extrapolated values were reported on a spreadsheet. After calculating the mean and standard deviation, data were compared with each other to rank overlay

production methods according to their marginal and sitting accuracy. The results were then statistically analyzed using a one-way analysis of variance (ANOVA) test.

RESULTS

The graphic in the Figure 7 aims to evaluate the repeatability of a model production method by showing the statistical analysis of the discrepancy between the tooth and the model measured with CTAn software. Regarding the sample 1 models, the only significant difference observed was between the first two replicates of the pAM-S ($p=0,0246$). For the Sample 2 models, the only significant difference detected was between the second and third PM replicates ($p=0,0025$).

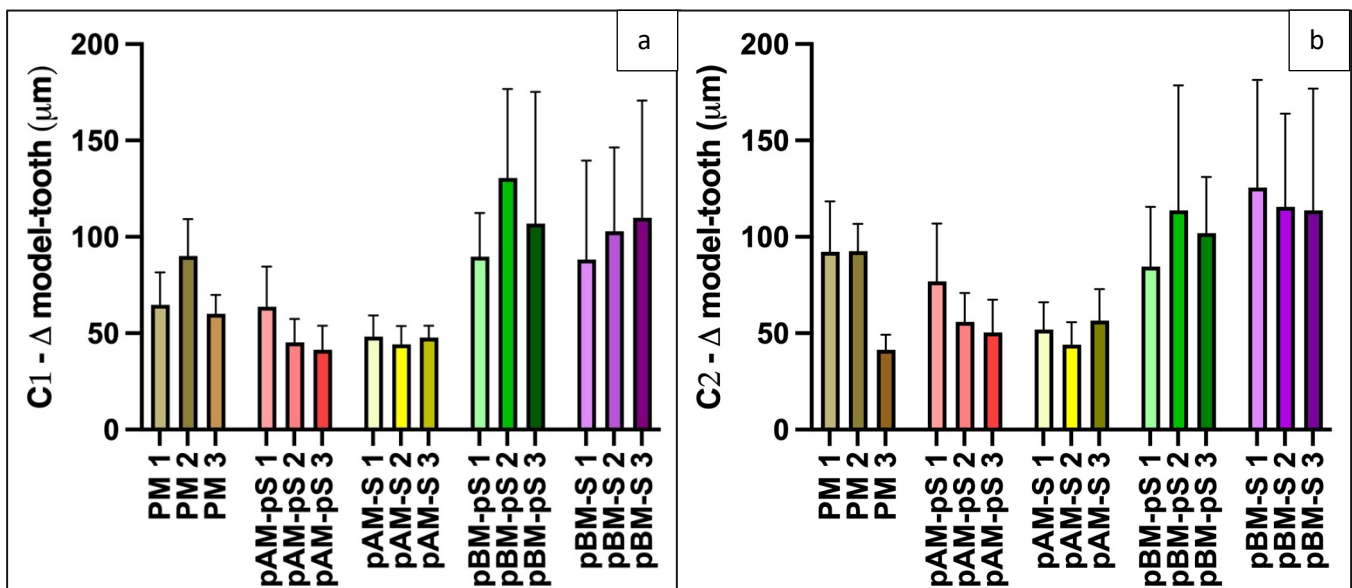


Figure 7. Discrepancy between tooth and models. Sample 1 (a) and sample 2 (b) replicates

The graph in Figure 8 shows the accuracy of the models produced using the traditional or digital workflow compared to the tooth, based on sample 1. The following statistical significance was found. pAM-pS and pAM-S were more accurate than PM ($p=0.0436$ and $p=0.0117$, respectively). PM was more accurate than pBM-pS ($p<0.0001$) and pBM-S ($p=0.002$), while pAM-pS was more accurate than pBM-pS ($p<0.0001$) and pBM-S ($p<0.0001$).

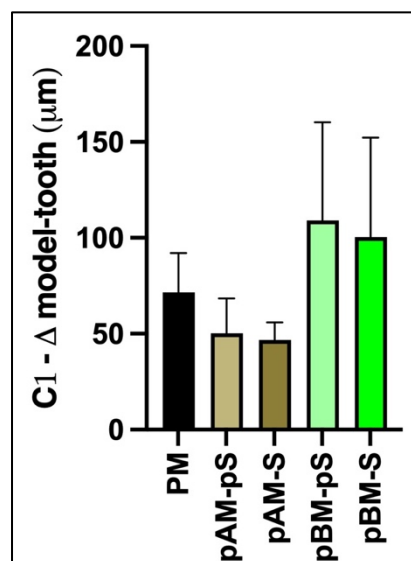


Figure 8. Accuracy of sample 1 models produced with CAD-CAM and conventional methods

The graph in Figure 9 shows the accuracy of the models produced by the traditional or digital workflow compared to the tooth, related to sample 2. The statistical significance showed as follows: PM is less accurate than pAM-S ($p=0.0213$), PM is

more accurate than pBM-pS ($p=0.0196$) and pBM-S ($p<0.0001$), pAM-pS is more accurate than pBM-pS ($p <0.0001$) and pBM-S ($p<0.0001$), pAM-S is more accurate than pBM-pS ($p<0.0001$) and pBM-S ($p<0.0001$).

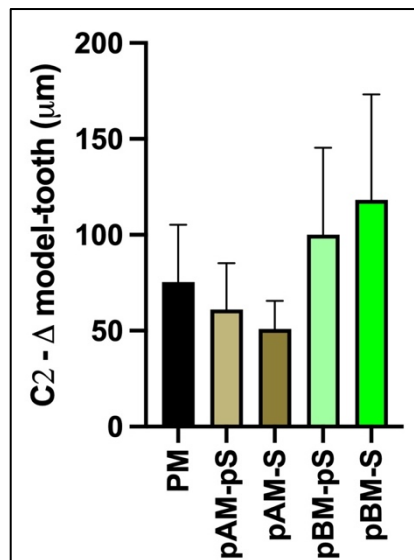


Figure 9. Accuracy of sample 2 models produced with CAD-CAM and conventional methods

The graph in Figure 10 shows the marginal fit of the overlays produced by the traditional and digital workflows in relation to sample 1. The following statistical significance was found: pBO-S was less accurate than pAO-pS ($p=0.0008$), pAO-S ($p=0.001$), pAO-R ($p=0.0045$), pBO-pS ($p=0.0018$) and pBO-R ($p=0.0196$).

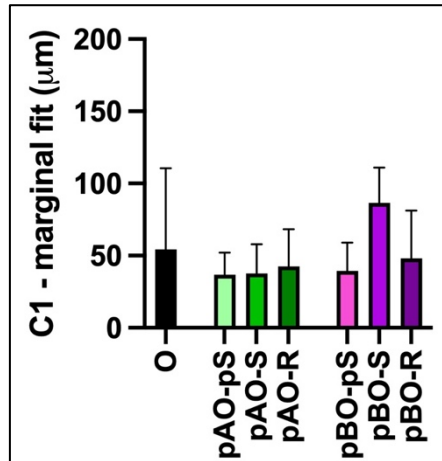


Figure 10. Sample 1 overlays marginal gap measures

The graph in Figure 11 shows the marginal fit of the overlays produced by the traditional and digital workflows in relation to sample 2. The statistical significance showed as follows. O was more accurate than pAO-S ($p < 0.0001$), pBO-S ($p < 0.0001$) and pBO-R ($p < 0.0001$). pAO-pS was more accurate than pAO-S ($p < 0.0001$), pBO-S ($p < 0.0001$) and pBO-R ($p < 0.0001$). pAO-S was more accurate than pBO-R ($p < 0.0001$) and less accurate than pAO-R ($p < 0.0001$) and pBO-pS ($p < 0.0001$). pAO-R was more accurate than pBO-S ($p < 0.0001$) and pBO-R ($p < 0.0001$). pBO-pS was more accurate than pBO-S ($p < 0.0001$) and pBO-R ($p < 0.0001$). pBO-S was more accurate than pBO-R ($p < 0.0001$).

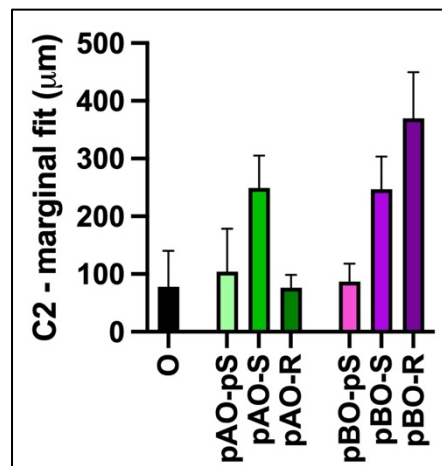


Figure 11. Sample 2 overlays marginal gap measures

The graph in Figure 12 shows the internal fit of the overlays produced by the traditional and digital workflows in relation to sample 1. The statistical significance showed as follows. O was more accurate than pBO-R ($p=0.0029$), pAO-pS was more accurate than pAO-R ($p=0.0284$) and pBO-R ($p<0.0001$), pAO-S was more accurate than pBO-R ($p<0.0001$), pBO-pS was more accurate than pAO-R ($p=0.0044$), pBO-S ($p=0.0281$) and pB-R ($p<0.0001$), pBO-S was more accurate than pBO-R ($p=0.0156$).

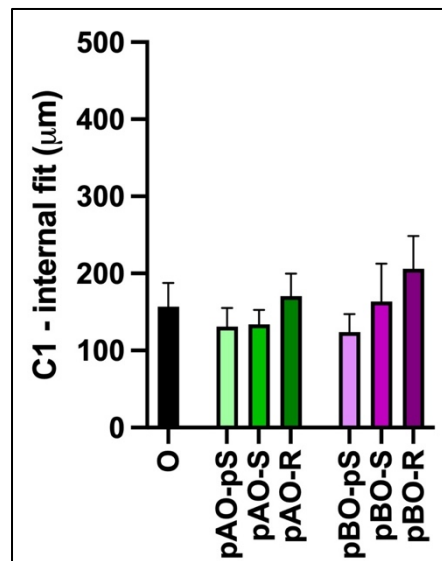


Figure 12. Sample 1 overlays internal gap measures

The graph in Figure 13 shows the internal fit of the overlays produced using the traditional and digital workflows in relation to sample 2. The statistical significance showed as follows. O was more accurate than pAO-S ($p=0.0001$) and pBO-R ($p<0.0001$). pAO-S was less accurate than pAO-pS ($p=0.0009$), pAO-R ($p=0.0018$), pBO-pS ($p<0.0001$), pBO-S ($p=0.0004$). pBO-R was less accurate than pAO-pS ($p<0.0001$), pAO-R ($p<0.0001$) and pBO-S ($p<0.0001$).

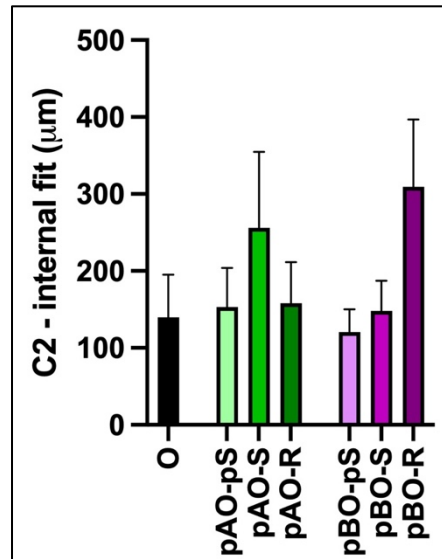


Figure 13. Sample 2 overlays internal gap measures

DISCUSSION

The first part of this study aimed to compare the accuracy and reproducibility of different methods of producing dental models (traditional method and two different 3D printers). A total of 30 models were produced, scanned with micro-CT and the resulting images processed and superimposed using 3D comparison software.

The results show that, with the exception of a few samples, there is no significant difference between the models produced by the same method, for both conventional and digital methods. The type of tooth preparation did not seem to affect the reproducibility of the models, either for the conventional or the digital method.

When comparing the different models with each other and with the natural tooth, the Asiga printer showed higher accuracy values compared to the natural tooth than the plaster models. The models produced with the Nobil Metal printer, on the other hand, showed lower accuracy values than the other two manufacturing methods. The presence of a pre-preparation scan of the tooth seems to positively influence the accuracy in the production of digital models in general. Anyway, the overlap between dental models of all examined groups shows clinically irrelevant discrepancy values, making all production methods suitable for clinical purposes.

Regarding the previous literature, Sim et al., comparing digital models with conventional models using 3D analysis software, concluded that the trueness and precision of the stone model were significantly better than those of the 3D printed model ($p < 0.001$) [38]. Similar results were obtained by Cho et al., who observed that in terms of the reproducibility and accuracy of the entire cast area, the conventional cast was significantly better than the digital cast [39]. However, more recent studies have shown that models produced using additive digital manufacturing are comparable to plaster models in terms of accuracy and trueness [40-42]. The results of this study agree with those of more recent studies in the literature. This is likely due to improvements in 3D printing technologies over the past decade, which have increased their accuracy and reliability, making them a more suitable tool for clinical purposes.

The second part of the study aimed to investigate the difference in marginal and internal accuracy of lithium disilicate overlays produced through digital and traditional workflows. Digital workflows have been shown to produce restorations with marginal and internal accuracy similar to the conventional method. For both samples examined, the internal fitting showed higher gap values than the marginal fitting regardless of the production method. The type of tooth preparation seems to influence the accuracy in the marginal and internal fit of the overlays produced, especially with regard to 3D printers. Tooth preparations with inclined planes and net edges appear to favor greater precision in defining the closing margins of 3D printed artefacts than interproximal boxes and side-to-side grooves. As previously observed for models, for the production of LD overlays the presence of a pre-preparation scan of the tooth seems to positively influence the accuracy of the final artefact. Rebasing the margins on a digital model appears to produce restorations with lower marginal fits than the traditional method. When comparing the two printers, the Asiga printer was shown to produce overlays with better marginal and internal accuracy values than the Nobil Metal printer in both samples observed.

A few previous studies have evaluated the accuracy of lithium disilicate onlay and inlay restorations fabricated from 3D-printed wax patterns compared to those fabricated using traditional techniques. Eftekhari Ashtiani et al. [35] compared lithium disilicate onlays produced by pressing patterns produced by different manufacturing methods: conventional method, conventional impression 3D printing and digital

impression 3D printing. The authors found that the two groups of 3D-printed indirect LD restorations had a slightly poorer fit than the conventionally fabricated onlays. However, all three groups showed clinically acceptable fit values. Similar results were obtained by Revilla-León et al., who measured the marginal and internal gap of handmade, milled and additive manufactured patterns for an LD onlay restoration using a Micro-CT test. The authors concluded that all the groups presented less than 100 µm marginal and internal gap, which is considered clinically acceptable, but the best marginal and internal fit was still obtained by the conventional handmade procedures [33]. Again, Homsy et al. compared the marginal and internal fit accuracy of lithium disilicate glass-ceramic inlays fabricated with conventional, milled, and 3D printed wax patterns [32]. In this study, however, the authors found out that three-dimensional printed wax patterns yielded fit values similar to those of the conventionally waxed inlays. Lithium disilicate glass-ceramic inlays produced from digital impressions and subtractive milling of wax patterns resulted in better marginal and internal fit accuracy than either conventional impression/fabrication or additive 3D manufacturing. Several studies have compared the fitting of LD crowns produced from different methods of manufacturing wax patterns. Ottoni et al. [7] evaluated the adaptation and fatigue behavior of LD monolithic crowns produced by press (combined with 3D-printing) and CAD/CAM milling techniques, observing that 3D printed group showed similar fatigue behavior than milled and resulted in smaller gap thickness at the occlusal region. The authors concluded that a more controlled

process can be achieved by replacing conventional restoration waxing with 3D printing, which in combination with the press technique produces lithium disilicate glass-ceramic monolithic crowns with good adaptation and high fatigue survival.

Similarly, Rodriguez de Abreu et al. [34], comparing fifty LD crowns fabricated with five different workflows, concluded that the conventional method showed no statistical differences in marginal discrepancy compared with methods using digital technology (scanner, software, 3D printer, or milling machine). Shamseddine et al. [36] found no significant differences between marginal, axial, and occlusal fit of LD crowns produced from subtractive milled wax patterns or patterns obtained from a digital manufacturing additive process. 3D printing production of wax patterns was found to be more accurate than other methods in a study conducted by Elfar et al. [29]. The authors observed that wax patterns for LD crowns produced with 3D printers showed higher marginal fit than those produced by milling or traditional method. Ottoni et al. [27], in addition to comparing the adaptation of LD crowns produced with additive and subtractive digital methods, investigated whether the type of tooth preparation can influence the accuracy of the final restoration. For the authors, the ideal combination of factors for all-ceramic crowns is chamfer abutment preparation, extraoral scanning, and the press technique combined with 3D printing.

The accuracy of lithium disilicate veneers produced by conventional and digital methods were also evaluated. Guachetá et al. [37] compared the marginal and internal fit of pressed LD veneers fabricated from a 3D printed castable wax resin versus a

manual waxing technique, concluding that there were no statistically significant differences.

On the other side, some research in literature argues that 3D printing is not the best alternative for the fabrication of indirect LD restorations nowadays. In a study where wax models of crowns produced with different methods were compared (subtractive manufacturing, 3D printer and conventional method), Çakmak et al. concluded that models produced with milling machines were more accurate than those produced with additive manufacturing or conventional method. However, the three manufacturing processes showed small deviation values, making all methods of producing castable models acceptable for clinical purposes [9]. Similar conclusions were reached by Kang et al. in a study comparing the three methods of producing castable models for the fabrication of lithium disilicate veneers [28].

CONCLUSION

This study aims to compare traditional and digital methods in the production of dental models and indirect lithium disilicate restorations. It also investigates the accuracy of two different 3D printers and the role of pre-preparation scanning of the tooth and the type of preparation itself on the final accuracy of the artefacts. For the production of dental models, the digital method has been shown to be as accurate as, or in some cases more accurate than, the traditional method.

This result is in line with the most recent literature, which confirms the suitability of using 3D printers to produce dental models instead of traditional plaster.

Regarding LD overlays, the digital method has been shown to produce restorations that overlap in precision with those produced by the traditional method. The choice of printer, as well as the type of tooth preparation used, has a significant influence on the marginal and internal accuracy of the final artefacts. In the digital workflow, taking a scan of the tooth before it is prepared can improve the accuracy of the restoration. In conclusion, the production of lithium disilicate overlays through a digital workflow, involving the use of intraoral scanners for impression taking and a CAD/CAM protocol resulting in a 3D-printed wax pattern, appears to be a viable clinical alternative to the traditional method in restorations.

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