Accuracy of Complete Digital Workflow for Fabrication of Implant-Supported FDPs: In-vitro Study in the Anterior Maxilla

A Thesis

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DEDICATION

To my beloved **parents**, your unwavering faith in my potential and the sacrifices you have made to ensure my education have been nothing short of extraordinary. Your guidance, wisdom, and constant encouragement have shaped me into the person I am today.

To my **siblings**, you have been my constant companions, cheering me on in every step of this academic pursuit. Your camaraderie and support have made even the most challenging moments more manageable.

As I complete this thesis, I recognize that you have been the wind beneath my wings, guiding me towards success with love, patience, and understanding.

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ABSTRACT

Objective: To assess the accuracy of fit of implant-supported, (Polymethylmethacrylate) PMMA screw-retained prostheses fabricated using complete digital workflow.

Materials and Methods: A partially edentulous maxillary 3D printed cast -Kennedy class IV- with two bone-level internal connection implants (Straumann Bone Level RC) placed at lateral incisors position (#7, #10) was used as the reference cast. A total of 50 (N=50) scans of the cast were acquired using the TRIOS scanner (TRIOS 4, 3Shape, Copenhagen, Denmark) in a controlled environment. The digital scans were exported in the Standard Tessellation Language (STL) format. The STL files were imported into CAD software (Exocad, DentalCAD version 3). Utilizing the software, a reference PMMA 4-unit implant-supported prototype prosthesis at the implant level (RC; Straumann®, Switzerland) was created. The assessment of prosthesis fit was carried out using the screw resistance test and radiographic analysis.

Results: The results of the screw resistance test revealed that 98% (N=49) of the PMMA implant-supported prostheses exhibited a fit that was considered clinically acceptable. However, when assessing the fit radiographically, it was found that all 50 prototypes (100%) achieved a clinically acceptable fit.

Conclusion: Within the limitations of this in vitro study, the accuracy of fit of implant-supported, PMMA screw-retained prosthesis fabricated using complete digital workflow was found to be clinically acceptable in the scenario of partially edentulous anterior maxilla.

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I. Introduction:

Computer-aided design and computer-aided manufacturing, commonly known as CAD/CAM, have transformed many industries, including dentistry. The implementation of this technology has revolutionized dentistry by enhancing the accuracy, efficiency, and speed of dental treatments.[1]. CAD/CAM technology has been used in dentistry for over 30 years. In 1985, Francois Duret developed the first dental CAD/CAM system, which was used to fabricate dental restorations.[2] The system used a scanning device to create a digital impression of the patient's teeth, which was then used to design the restoration using computer software. The design was then sent to a milling machine, which produced the restoration from a block of ceramic material. Since then, CAD/CAM technology has evolved significantly, with new materials and software to improve the accuracy and aesthetics of restorations.[3] Today, CAD/CAM systems are widely used in dentistry, and they have become an essential tool for many dental practices. The traditional method of dental restoration involved taking dental impressions, creating a model, and then utilizing this model to create a restoration.[4] This process is time-consuming and required multiple visits. CAD/CAM technology has made it possible to complete the entire dental restoration in a single visit.[5] Digital workflow in dentistry has three main components. The workflow starts with Data Acquisition, which is the process of obtaining the required data. The process starts with taking a digital impression of the patient's mouth using an intra-oral scanner.[6]

The application of digital imaging in the field of dental impression making has a historical background that traces back to 1980 when Dr. Werner Mörmann of Zurich, Switzerland, pioneered this concept.[7] Dr. Mörmann, in collaboration with Dr. Marco Brandestini,

embarked on experiments involving the fabrication of dental restorations, a century after the introduction of fired porcelain in restorative dentistry.[7][8] In 1980, Dr. Mörmann obtained the first patent for dental scanning, and by 1982, the first handheld intraoral 3D scanner was developed, although it required further refinement. In 1983, employing the Principle of Active Triangulation, a significant breakthrough was achieved by successfully generating the first optical impression of an inlay directly chairside.[7][8] Subsequently, in 1985, the first functional 3D camera for intraoral imaging was introduced, known as the RedCam, which utilized an infrared light-emitting diode as the light source. [8] The RedCam was later replaced by the BlueCam in 2009, offering scanning precision of 25 μm using blue light. Presently, we have advanced technologies such as Sirona's OmniCam (2012) and the more recent Primescan (2019), which enable real-time, full-color, high-definition video scanning.[8]

Since the inception of intraoral scanning in the 80s, there has been a continuous cycle of advancements in this field. Initially, the scanners used to capture static images, necessitating the use of intraoral scanning spray. However, over time, significant progress has been made, leading to the development of contemporary technologies that enable the capture of high-quality color videos without the need of scanning spray.[8] In recent years, there has been a notable surge in the proliferation of optical intraoral scanners (IOS) utilizing diverse technologies. The selection of a particular technology can significantly influence its suitability and effectiveness in clinical settings.[9][10]

Multiple research studies have conducted comparative analyses between traditional and digital impressions, considering perspectives from both the patient and the providers.[11] It was demonstrated that overall treatment time and impression time is less with the digital impressions when compared to the traditional impressions.[12] Multiple studies have shown

that inexperienced dental students compared to experienced clinicians preferred the digital impressions over the conventional ones.[13][14] Digital impressions were the preferred method as it was described as being easier and more time efficient compared to the traditional impressions.[13]. The digital impression technique was favored by patients over the conventional impression technique, indicating a higher level of patient satisfaction.[15]

The accuracy of intra-oral scanners was a subject of interest to many dental clinicians and researchers, prompting numerous studies comparing the accuracy of digital impressions to the conventional dental impressions in different clinical scenarios.[16][17][18][19][20][21][22][23][24][25][26][27][28][29][30] It's crucial to understand the definition of accuracy of a measurement method. According to the International Organization for Standardization ISO, accuracy of a measurement method is described by "trueness" and "Precision".[31][32]

"Trueness" is a term used to describe the level of agreement between the average of multiple test results and the true or accepted reference value.[31] On the other hand, "precision" refers to the level of agreement between individual test results.[31]

Several factors contribute to the overall quality of a digital impression, encompassing the technology employed in the intraoral scanning device. [9], The intraoral scanning device technology plays a critical role, as different devices may utilize distinct scanning mechanisms and sensor technologies, which can impact the level of detail captured and the overall precision of the impression. [9] Additionally, the scanning environment, including factors such as lighting conditions and patient comfort, can influence the ease and effectiveness of the scanning process. [33] The operator's experience and proficiency in handling the scanning device and executing the scanning technique are crucial factors that can significantly impact

the quality of the digital impression. [34], Furthermore, the surface characteristics of the object being scanned, such as the presence of reflective surfaces or the translucency of certain materials, can pose challenges in accurately capturing the desired information. [35][36] Finally, the chosen scanning technique, including factors such as the scanning path, and the angle of approach, can influence the level of detail and accuracy achieved in the digital impression. By considering and optimizing these various factors, clinicians can enhance the quality and reliability of digital impressions in dental practice. [37][33]

After data acquisition, analysis, and processing of the data and designing the restoration is done using Computer-Aided Design (CAD) software. CAD software provides dental professionals with powerful tools and functionalities to digitally create, modify, and customize dental structures with exceptional precision and accuracy.[1] By utilizing three-dimensional digital models obtained through intraoral scanners or cone beam computed tomography (CBCT), CAD software enables detailed and comprehensive virtual representations of the patient's dentition, aiding in the design of various dental restorations.[38] These digital models can be manipulated and optimized to achieve optimal functional and aesthetic outcomes.[3] The software allows for fine-tuning of parameters such as shape, size, contour, occlusal morphology, and material selection, tailoring the restoration to the patient's unique anatomical requirements and preferences.[5] Moreover, CAD software offers tools for analyzing occlusion, evaluating interproximal contacts, and ensuring proper alignment with adjacent teeth. [3] The virtual design process facilitates efficient communication and collaboration between dental professionals and dental laboratory technicians, enabling seamless integration

and exchange of information. Furthermore, CAD software streamlines the workflow by eliminating the need for physical models and traditional manual wax-ups, reducing material waste, and enhancing overall efficiency.[39] The ability to visualize the final restoration in a virtual environment allows for better patient communication and involvement in treatment planning. [40]CAD software has opened new avenues for digital dentistry, enabling the creation of complex dental structures, guided implant surgery, and computer-assisted orthodontics.[41] With continuous advancements in CAD software and integration with computer-aided manufacturing (CAM) systems, the future holds tremendous potential for further innovation, allowing for more sophisticated designs, improved accuracy, and enhanced patient-centered care in dentistry.[3]

And finally converting the 3D design into an object by Computer-Aided Manufacturing (CAM). [5] CAM systems are either based on Subtractive or Additive manufacturing technology. The subtractive manufacturing process starts with the creation of a digital model using computer-aided design (CAD) software, which is then used to guide the milling machine. The milling machine can produce highly accurate and precise dental restorations from a variety of materials, such as ceramics, resins, and metals, allowing for the creation of complex shapes and fine details.[5] Additive manufacturing (AM) -also known as three-dimensional printing or 3D printing- is defined by the American Society for Testing and Materials (ASTM) as "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies."[5] The integration of CAD/CAM technology has transformed the landscape of dentistry by providing a diverse range of benefits over conventional methods of restorative dentistry. With CAD/CAM, dental restorations can be designed with a high level of accuracy and precision. Furthermore, the technology enables

the creation of highly customized restorations that can be fabricated in a single visit, resulting in reduced chair time for patients and dentists. [42] However, there are certain disadvantages that should be considered before implementing CAD/CAM in dental practices. One of the major challenges associated with CAD/CAM is the high cost of equipment, which may require significant investment for the initial set-up. [43] Additionally, CAD/CAM technology requires specialized training and expertise to operate effectively, which can limit the accessibility of the technology to certain practitioners. Hence, while CAD/CAM technology has several benefits in dentistry, it is important to carefully weigh the advantages and disadvantages before implementing this technology in a dental practice.

The field of implant dentistry has experienced significant advantages as a result of the advancements made in digital technologies within the dental industry. The implementation of various technologies, including 3D radiographic imaging, intraoral optical scanners (IOSs), virtual implant planning software programs, computer-guided implant placement, and computer-aided design and computer-aided manufacturing (CAD-CAM), has led to significant advancements in the field of dental implant therapy. [24] These technological tools have played a crucial role in optimizing the efficiency and effectiveness of the treatment process while improving the predictability and reproducibility of treatment outcomes. [24] The utilization of 3D radiographic imaging enables clinicians to obtain highly detailed and precise images of the patient's oral structures, facilitating accurate treatment planning. Intraoral optical scanners have revolutionized the capturing of digital impressions, eliminating the need for traditional physical impressions, and enhancing the accuracy of prosthesis fabrication. Virtual implant planning software programs offer a comprehensive platform for meticulous preoperative

planning, allowing clinicians to assess bone quality and quantity and virtually position implants for optimal results. Computer-guided implant placement further enhances precision by providing real-time guidance during the surgical procedure, ensuring precise implant positioning as per the virtual plan. Moreover, CAD-CAM technology has significantly streamlined the design and manufacturing process of custom implant restorations, resulting in improved fit and aesthetic outcomes. [44] The integration of digital technologies into implant dentistry has resulted in enhanced predictability across both clinical and laboratory procedures, thereby contributing to improved treatment outcomes with a higher degree of confidence and accuracy.[45]

The long-term success of implant-supported prosthesis depends on the accuracy of the three dimensional prosthesis fit on the implant-abutment junction.[46] [47]The literature extensively discusses the importance of proper fit in implant-supported dental restorations.[48] Unlike natural teeth, osseointegrated implants lack the ability to compensate for minor inaccuracies in the prostheses, as they possess limited mobility.[49] Their sensory discrimination is also less pronounced compared to natural teeth due to lack of Periodontal ligament.[50] The demand for accurately fitting implant-supported prostheses is even higher when fabricating screw-retained restorations.[48] When there is an implant-prosthesis misfit, The screw-retained prosthesis is less forgiving due to the lack of cement layer that may compensate for the misfit.[51][52] Due to cumulative errors introduced during each clinical and laboratory step, a certain degree of inaccuracy is inevitable. [48] Defining the passivity of a prosthesis is a controversial topic. Despite the controversy, the passive fit is a term used to describe a

prosthesis that doesn't produce stress/strain on the prostheses, implant, and/or surrounding structures.[53]

The etiology of misfit is typically multifactorial in nature.[47] There are several factors that affect the prosthesis fit which include: implant alignments, prosthesis length, impression materials and techniques, framework design and fabrication process ,and the experience level of the clinical provider and the dental technician. [47]

Implant framework misfit can lead to a range of issues, including mechanical complications of the prostheses, implant, or biologic complications in the surrounding tissue.[47][54] Mechanical complications include screw loosening , screw fracture, chipping of the veneering material or prosthesis fracture.[55] Biologic complications may manifest as adverse tissue reactions, pain, tenderness, marginal bone loss, and loss of implant integration.[47]

To date, the scientific literature has not provided a specific determination regarding the magnitude of a defined threshold for an acceptable level of implant-prostheses misfit.

Brånemark established a standard for passive fit in frameworks, considering a gap of 10 µm or less between the framework and abutment as acceptable.[56] On the other hand, Jemt proposed a different criterion, suggesting that a framework misfit of less than 150 µm was considered acceptable.[57] These criteria reflect different perspectives on what constitutes an acceptable level of misfit in implant-supported frameworks.

A recent systematic review attempted to determine the biological and mechanical tolerance of misfit gathering information from available clinical and laboratory studies in the literature.[58] It was concluded that mechanical complications to implant-prosthesis misfit is far more critical than biological complications.[58]

Various clinical and laboratory techniques have been proposed to evaluate the passive fit of implant-supported restorations; however, none of them can be solely relied upon.[55][52][59][60] It has been recommended to combine more than one method of assessment to compensate for the limitations of each assessment technique.[53]

1. Visual and Tactile Sensation:

Visual assessment combined with tactile sensation is usually the first step of evaluating the implant prosthesis fit. Visual assessment can be improved using illumination and magnification.[53] The limitation of this method is pronounced when clinically inspecting the fit of a prosthesis with subgingival margins.[47] A study conducted by Christensen have demonstrated that clinicians tend to reject the presence of a marginal opening that is approximately 30 µm in size when it is located supragingival. Conversely, when the marginal opening is located subgingival, clinicians are more accepting of a larger opening measuring around 120 µm. These findings highlight the variation in clinicians' tolerance for marginal discrepancies .[61]

2. Alternate Finger Pressure:

Henry proposed a convenient and straightforward technique for the initial evaluation of implant framework fit.[62] This method involves seating the prosthesis and applying finger pressure alternatively over one distal abutment and then the other. By employing this approach, a preliminary assessment of the gross misfit between the framework and the abutments can be

conducted, providing valuable insights into the overall compatibility and alignment of the implant-supported prosthesis.[47]

3. Radiographic Imaging:

Peri-apical radiographs are used to assess the fit of implant-supported framework. Achieving parallelism between x-ray film and implant-abutment joint is crucial to effectively identify misfits that could potentially be overlooked due to overlaps caused by malalignment.[53] *Cameron* et al. recommended that the tube head should be positioned at an angle of less than 20 degrees perpendicular to the long axis of the implant to obtain a diagnostic radiograph. [63] Radiographs are of a great importance to evaluate implant supported frameworks with sub-gingival margins.

4. Sheffield Test:

Also known as one screw test, This test is particularly advantageous when assessing the fit of long span implant-supported frameworks, as it allows for the identification of magnified vertical discrepancies that may occur at the opposite terminal abutment.[47] When the implant-Prostheses joint is located supragingival, direct vision can be used to detect the vertical gap combined with ilumination and magnification. However, periapical radiographs will be needed in case of subgingival margins [53]

5. Screw resistance test

In 1991, Jemt introduced the screw resistance test as a method to assess the level of misfit in implant-supported frameworks.[57] Based on his clinical experience, Jemt determined that a

misfit of 150 µm, equivalent to half the distance between the prosthetic gold screw threads of Nobel Biocare, was considered clinically acceptable. The test involves sequentially tightening gold screws, starting from the implant closest to the midline, until initial resistance is encountered between the screw head and the framework. Subsequently, a maximum of one half turn (180 degrees) is allowed to fully seat the screw and achieve a torque measurement of 10 to 15 Ncm. If more than a half turn is required to achieve the desired screw seating and torque, it is indicative of a misfit in the framework. This test provides a practical and standardized approach for evaluating the fit of implant-supported frameworks.[47]

6. Disclosing Materials:

Various materials, including wax, elastomeric materials, powered spray, and pressure-indicating paste, have been employed as disclosing agents to assess the fit of implant-supported frameworks. These materials serve the purpose of revealing any discrepancies or gaps in the fit of the framework, allowing for a thorough evaluation of its accuracy and precision. By applying these disclosing materials, clinicians can visually identify areas where the framework may exhibit misfit, enabling necessary adjustments or corrective measures to be taken.[53] Disclosing media have been utilized as supplementary tools alongside the screw resistance test to assess the fit of frameworks. These disclosing materials prove useful for evaluating both supragingival and subgingival margins, enabling a comprehensive assessment of the framework fit.[47]

7. Torque-angle analysis:

The utilization of torque-angle signature analysis presents a potential approach for objectively evaluating the fit between a framework and implant analogs or implants.[60] A device called

OsseoCare, developed and marketed by Nobel Biocare, was initially designed to assess bone resistance and quality during implant surgical placement. However, it could also be employed for monitoring the torque-angle signature analysis when seating screw-retained implant prostheses. This application of the device would enable a comprehensive assessment of the fit and stability of the framework during the screwing process.[60]

Apart from the clinical techniques employed for assessing the fit of an implant-supported prosthesis, several in-vitro methodologies have been used including photogrammetry[64], microscopic analysis[52], Photo-elastic analysis[65], strain gauge analysis (SGA)[66], and finite element analysis (FEA).[67]

Consequently, various corrective measures have been introduced to reduce misfit in implant frameworks, including the utilization of verification devices, the casting of low-fusing metals, the implementation of different impression techniques, the casting of the framework in sections, post-fabrication sectioning, and the application of soldering techniques. These approaches aim to address and rectify any discrepancies in the fit of the framework, contributing to improved overall precision and accuracy of the final restoration. [58] A systematic review was conducted to compare the fit of screw-retained implant frameworks fabricated using different methods. The findings of the review indicated that computer-aided design and computer-aided manufacturing (CAD/CAM) consistently yielded the most reliable and consistent outcomes in terms of framework fit.[68][69]

CAD/CAM technology offers a notable advantage by eliminating several traditional fabrication steps, such as waxing, investment casting, and polishing. These conventional materials and

procedures can introduce inherent inaccuracies, which tend to amplify with larger frameworks. However, CAD/CAM overcomes these limitations by providing a streamlined digital workflow that directly translates digital designs into physical restorations. This advanced technology allows for precise and accurate fabrication without the need for intermediate steps, resulting in improved overall accuracy and fit of the final prosthetic restorations. [70]

II. Research Aims/Hypothesis:

To assess the accuracy of fit of implant-supported, (Polymethylmethacrylate) PMMA screw-retained prostheses fabricated using complete digital workflow.

Thereby our research hypothesis is:

The accuracy of fit of digitally fabricated, implant-supported, PMMA fixed dental prostheses is clinically acceptable, in the scenario of a 4-unit prostheses in the anterior maxilla.

III. Significance:

To the investigators' knowledge, the accuracy of fit of digitally fabricated, implant supported, PMMA prototype prostheses have not been investigated yet.

IV. Materials and Methods

In this study, a 3D printed cast – using M2 Carbon printer (Carbon®, Redwood City, CA, USA), - of a partially edentulous maxillary arch was utilized. The cast represents a Kennedy class IV

situation, indicating multiple missing anterior maxillary teeth. Two bone-level internal connection implants, Straumann Bone Level RC implants, placed at the positions corresponding to the lateral incisors (#7 and #10) on the cast. The two implants are oriented at an angle of 5° relative to each other, replicating the scenario of optimal implant placement. This experimental setup aims to simulate a common clinical scenario of missing anterior teeth treated by digitally fabricated fixed implant-supported prostheses.

1. Data acquisition:

Two implant analogs on the master reference cast were fitted with scan bodies composed of polyetheretherketone (PEEK) material, specifically the CARES Mono Scan Body from Straumann® (Switzerland). These PEEK scan bodies were securely inserted into the implant analogs and tightened manually.

A total of 50 scans of the cast were acquired using the TRIOS scanner (TRIOS 4, 3Shape, Copenhagen, Denmark) in a controlled environment. The scanning procedure was performed by a single provider to ensure consistency and minimize variability. Before initiating the scanning process, a calibration tip was used to calibrate the scanner, ensuring accurate measurements and data acquisition. To maintain the accuracy of the scans, the calibration process was repeated after every 10 scans. This rigorous calibration protocol was implemented to ensure reliable and precise data collection throughout the scanning procedure. The scanning protocol employed consisted of an initial capture of the occlusal and palatal surfaces, followed by the buccal surfaces. This sequential approach was selected due to its demonstrated superior precision compared to alternative scanning strategies.[37] The digital scans were exported in the Standard Tessellation Language (STL) format.

2. Computer Aided Design (CAD)

The STL files were imported into CAD software (Exocad, DentalCAD version 3) for further analysis and design. Utilizing the software, a reference PMMA 4-unit implant-supported prototype prosthesis at the implant level (RC; Straumann®, Switzerland) was meticulously created. The implant positions were detected by selecting appropriate scan bodies (RC; Straumann®, Switzerland) from the Straumann® group library within the software. This process was performed for each STL file (N=50), thereby generating fifty Prototype designs.

3. Computer Aided Manufacturing (CAM)

Subsequently, the designs were transferred to the PrograMill PM7 milling machine (Ivoclar Vivadent, Amherst, NY, USA) for the fabrication process. A low translucency LT Telio® CAD PMMA block with dimensions of 98.5-20mm in shade A1 (Ivoclar Vivadent, Germany) was selected for the milling procedure. After completion of the milling process, individual porotypes were sectioned from the PMMA block using a laboratory carbide bur (H79E.11.040 HP E-Cutter Carbide, Brasseler, USA).

In order to fabricate the screw-retained implant-supported PMMA prosthesis, RC Variobase® Titanium base abutments designed for Bridge/Bar Cylindrical with a diameter of 4.5mm and a height of 3.5mm (Straumann®, Switzerland) were chosen. The cementation of the Titanium abutments to the PMMA prototype was accomplished using auto-curing Multilink Hybrid Abutment composite cement, along with SR Connect and Monobond® Plus (Ivoclar Vivadent,

Germany). The cementation procedure was carried out manually by a single provider, adhering to the instructions provided by the manufacturer.

Prostheses fit assessment

Before conducting the fit assessment tests, each prototype underwent a trial fitting on the reference cast and was carefully examined for the presence of any proximal contacts that could potentially affect the fit of the prosthesis. Whenever proximal contacts were identified, they were promptly eliminated to ensure optimal prosthesis fit.

1. Screw Resistant test:

The assessment of prosthesis fit was carried out using the screw resistance test, which was conducted by two skilled clinicians in a blind fashion. Each prototype of the was placed on the master cast for the purpose of fit evaluation. The prosthesis was manually tightened, adhering to a standardized method of tightening. A misfit was identified if the screw required more than a quarter turn to achieve the desired torque following the initial resistance.

1. Peri-apical Radiographs:

Radiographic assessment was conducted to evaluate the fit of the prototypes. Standardized digital radiographs were acquired using the long cone parallel technique, ensuring that the X-ray beam was perpendicular to the long axis of the implant-abutment junction for all prototypes.

Prior to capturing the radiographs, the prosthesis was torqued to 15 Ncm on both implants. A total of 100 radiographs were taken, with two radiographs obtained for each cast representing the positions of #7 and #10. To enhance reliability and consistency, all radiographs were obtained using the same sensor, X-ray machine, and film holder (Rinn centrator bite; Dentsply Rinn, Elgin, IL, USA) under the supervision of a single operator to ensure parallelism in the radiographic images.

V. Data Analysis

- Sample Size Calculation:

A sample size calculation was conducted using nQuery Advisor v. 9.1.1.0 (Statistical Solutions Ltd., Cork, Ireland). Because the aim of the study did not call for an assessment of statistical significance, the calculation was performed to ensure adequate precision of the estimated percentage of fit (as quantified by the margin of error of a 95% confidence interval) rather than power. The assumed percentage of fit for the calculation was based on previous study. [71] The calculation determined that a sample size of n=50 was adequate to obtain a two-sided 95% confidence interval with a margin of error of less than 10%.

- Statistical Analysis:

Descriptive statistics (frequencies and percentages) was calculated. Two-sided 95% confidence intervals was obtained using exact binomial confidence intervals. Inter-rater reliability was assessed via Cohen's kappa. SPSS v. 28 (IBM Corp., Armonk, NY, USA) was used in the analysis.

VI. Results

The results of the screw resistance test revealed that 98% (N=49) of the PMMA implant-supported prostheses exhibited a fit that was considered clinically acceptable. However, when assessing the fit radiographically, it was found that all 50 prototypes (100%) achieved a clinically acceptable fit. Subsequently, in cases where misfits were identified during the initial evaluation, re-cementation of the titanium abutments was performed to address any potential cementation errors that contributed to the presence of misfits.

VII. Discussion

The aim of this in-vitro study is to evaluate the accuracy of fit of digitally fabricated implant-supported, screw-retained PMMA prostheses in the scenario of 4-unit prostheses in the anterior maxilla. The research hypothesis was accepted that the accuracy of fit of digitally fabricated, implant supported, PMMA fixed dental prostheses was clinically acceptable.

The findings of the current study showed that 98% of the implant-supported, screw-retained PMMA prostheses fabricated utilizing complete digital workflow exhibited clinically acceptable fit on the master model when assessed using the screw resistance test. Moreover, radiographic assessment using per-apical x-rays displayed 100% clinically acceptable fit.

These findings align with a previous study conducted by *Rutkunas* et al.[72], where it was observed that restorations created through a digital workflow exhibited a significantly superior level of passive fit when compared to restorations fabricated using a conventional workflow. The implementation of a digital workflow led to a substantial enhancement in the precision and accuracy of fit for the restorations, highlighting its potential as a superior method of fabrication.

In a recent randomized clinical trial [73], the clinical fit and time required for adjustments were compared between implant-supported crowns produced through a partially digital workflow and a fully digital workflow in partially edentulous participants. The findings indicated that the fully digital workflow, known as the "Cast-free" approach, was more time efficient when compared to the partially digital workflow, referred to as the "Model-based" approach, for the fabrication of fixed partial dentures. [73] Specifically, the parameters of occlusal adjustment time and total adjustment time were significantly shorter for the fully digital workflow compared to the partially digital workflow. These results highlight the time-saving benefits associated with implementing a fully digital workflow for the production of implant-supported restorations. [73]

Franca et al. assessed the precision of fit of three-unit fixed dental prostheses (FDPs) constructed from frameworks fabricated through three different methods: zirconia and Co-Cr alloys using a CAD/CAM system, zirconia via copy-milling, and a Co-Cr alloy through conventional casting.[74] The results revealed significant differences in terms of accuracy among the fabrication techniques employed. CAD/CAM fabricated frameworks demonstrated superior vertical fit and exhibit lower variability when compared to frameworks fabricated through copy-milling and conventional methods.[74]

Several clinical studies have conducted comparisons between conventional and digital workflows, evaluating factors such as clinical accuracy, cost/time efficiency, esthetics, and patient preference.[75][76][21] Across all the studies reviewed, it was consistently observed that the accuracy of both workflows was comparable. However, the digital workflow exhibited advantages in terms of being more time-efficient and cost-effective compared to the conventional

workflow. On the other hand, one study focusing on esthetics outcomes revealed that the conventional workflow resulted in superior esthetic outcomes compared to the digital workflow.[76]

In our study, we observed a 100% rate of clinically acceptable prostheses fit when assessed through radiographic evaluation, while a 98% rate was achieved when utilizing the screw resistance test. This disparity in outcomes could be attributed to the direct evaluation of fit between the prosthesis and implant abutments facilitated by the screw resistance test. In contrast, radiographic assessments, such as per-apical x-rays, indirectly evaluate fit by examining the proximity of the prosthesis to implant components. Although radiographs provide valuable information concerning the overall position and alignment of the prosthesis, they may not possess the same level of sensitivity as the screw resistance test in detecting subtle misfit or discrepancies that could potentially impact clinical performance.

This misfit could potentially be attributed to an error introduced during one of the digital workflow steps. The digital workflow begun with the acquisition of a digital impression of the master cast, utilizing implant scan bodies.

Multiple systematic reviews have been conducted to assess the accuracy of intraoral scanning in the context of dental implants.[48][77] These reviews have examined various factors, including the distance between implants, implant location and depth, and scanning environment. Collectively, these reviews have concluded that implant scan bodies, despite being complex transfer devices with numerous variables, offer a valid alternative to conventional impressions for single and multiple implant restorations.[8]

By utilizing a distinct scan body, an intraoral scanner is capable of capturing its morphology, enabling the computer to digitally reconstruct the acquired image along with the neighboring teeth, facilitating the positioning of a virtual implant analog using surface-matching software.[8][77]

When choosing a scan body, several factors can influence the scanning quality and effectiveness of the selected scan body. These factors include: the material and geometry of the scan body, its compatibility with the design software, initial cost, and reusability. [77] Certain scan bodies are manufactured using PEEK material throughout, including the connection with the implant, while others combine PEEK for the scan region and metal for the connection interface. The utilization of a metal connection offers enhanced stability and durability in the interface with the implant. Consequently, this metal interface allows for increased clinical applications before necessitating replacement of the scan body[8] In a study conducted by *Sawyers* et al., the impact of multiple uses of implant scan bodies on the accuracy of partially dentate implant casts was investigated. [78] The specific number of times a scan bodiy can be reused without compromising the quality of the digital scan has not yet been thoroughly investigated. However, factors such as the material of the scan bodies and the sterilization technique employed are anticipated to influence the number of allowable uses.

In a recent clinical study, the 3-dimensional accuracy of conventional and digital workflows was compared in the context of restoring partially edentulous patients with two implants. The study revealed that a conventional implant impression technique exhibited superior accuracy when compared to digital impressions. The findings indicate that digital implant impressions resulted in significant distance and angulation errors that hindered the fabrication of well-fitting

restorations for patients with partial tooth loss.[16] The high level of accuracy observed in our study can potentially be attributed to the ideal angulation between the implants, -approximately 5 degrees-. This implant angulation contributed to a more predictable workflow, resulting in enhanced precision and accuracy in our findings.

Studies examining the accuracy of digital impressions primarily concentrate on evaluating the trueness and precision of the scan. Trueness refers to the degree of proximity between the scanned surface and its exact measured value, essentially measuring how closely the average results align with the precise measurements. Precision, on the other hand, assesses the consistency of obtaining the same result with repeated scanning. The combined influence of trueness and precision establishes the overall accuracy of the digital scan.[8]

The second step in the digital workflow is the design of the prostheses computer-aided design (CAD). The accuracy of transferring the implant location digitally has recently emerged as a significant research interest.[8] An in-vitro study demonstrated that the manufacturing tolerances of implant scan bodies (ISBs) have a significant impact on the accuracy of transferring the implant position from the intraoral recording to the digital cast. This highlights the importance of taking these tolerances into account when digitizing implant impressions.[79]

Prostheses that are designed using computer-aided design (CAD) applications are manufactured using digital dental manufacturing (DDM) devices. These devices can be categorized into subtractive manufacturing technology (SMT) and additive manufacturing technology (AMT). Subtractive manufacturing technology, predominantly relying on conventional computer numerical control (CNC) milling, is the more commonly employed method. [8]

Another factor could contribute to the high success rate we had in the study is the use of two non-engaging implant abutments. Internal connection implants offer the option of utilizing engaging or non-engaging abutments. Non-engaging abutments are particularly suitable for multiple-unit implant-supported screw-retained fixed partial dentures (FPDs) as they can accommodate non-parallel implants.[59][80]. Engaging abutments, on the other hand, are commonly recommended for single crowns but can also be utilized in FPDs when the implants are positioned in almost parallel alignment.[81] Combining engaging and non-engaging abutments can enhance the stability of FPDs and potentially improve the prosthesis fit and the long-term integrity of the implant-abutment junction. [82] Nonetheless, the current scientific literature lacks adequate evidence to fully support this approach, and further investigations involving clinical and laboratory studies are warranted. [59]

The main limitation of our study is the In-vitro nature of the research. In-vitro extra-oral scanning does not have the same challenging factors compared to the in-vivo intra-oral scanning. Some of the factors that might affect the intra-oral scanning quality are the presence of saliva, limited mouth opening and anatomical restrictions. Furthermore, extra-oral scans are typically less demanding and may exhibit a higher level of accuracy compared to intra-oral scans. Another limitation is testing a single clinical scenario which is the partial edentulism in the anterior maxilla restored with 4-unit PMMA screw retained implant-supported prosthesis. Therefore, it is crucial to exercise caution when interpreting the findings of this study as they pertain to the success rate observed within controlled laboratory conditions characterized by an optimal scanning environment and ideal implant angulation.

Further investigations are warranted to evaluate these outcomes in clinical settings and diverse clinical scenarios.

VIII. Conclusion

The accuracy of fit of implant-supported, PMMA screw-retained prosthesis fabricated using complete digital workflow was found to be clinically acceptable in the scenario of partially edentulous anterior maxilla.

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APPENDICES

Appendix A: Tables

Table.1: Frequencies, Percentages, Cumulative Frequency, Cumulative Percentage:

Screw resistance Test (n=50)				
Screw resistance Test	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	49	98.00	49	98.00
1	1	2.00	50	100.00

Table.2: Binomial Proportion:

Binomial Proportion (n=50)	
Screw resistance Test = 0	
Proportion (P)	0.9800
ASE	0.0198

Table.3: Clopper-Pearson Interval:

Confidence Limits for the Binomial Proportion (n=50)		
Proportion = 0.9800		
Type	**95% Confidence Limits**	
Clopper-Pearson (Exact)	0.8935	0.9995

Table.4: Cohen's Kappa coefficient

Simple Kappa Coefficient			
Estimate	**Standard Error**	**95% Confidence Limits**	
0.4845	0.3060	-0.1153	1.0000

APPENDICES

Appendix B: Figures

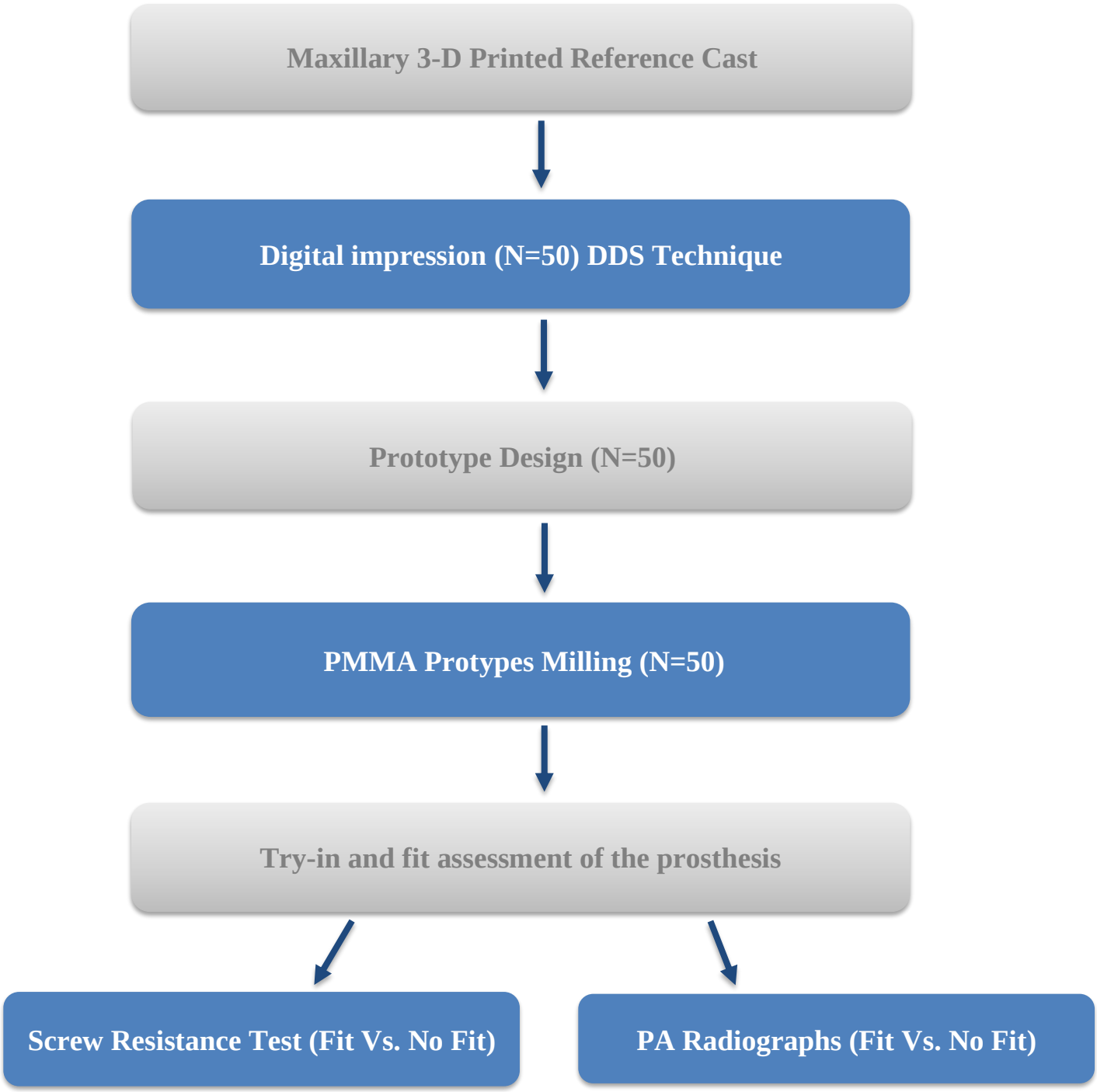

Figure.1: The flowchart of the study

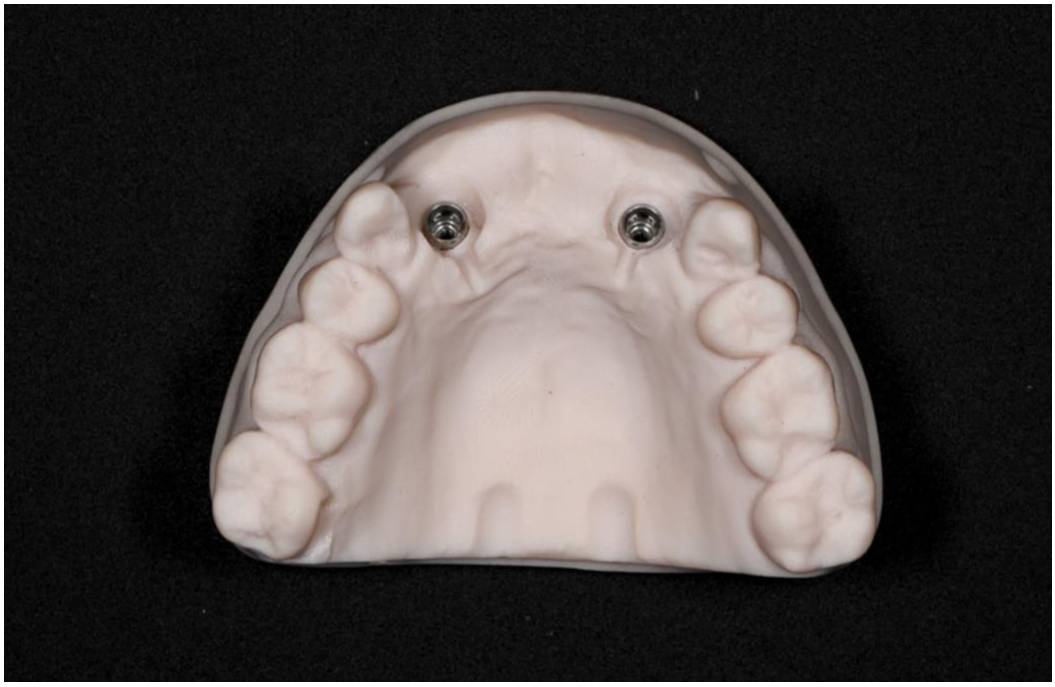

Figure.2: Master cast

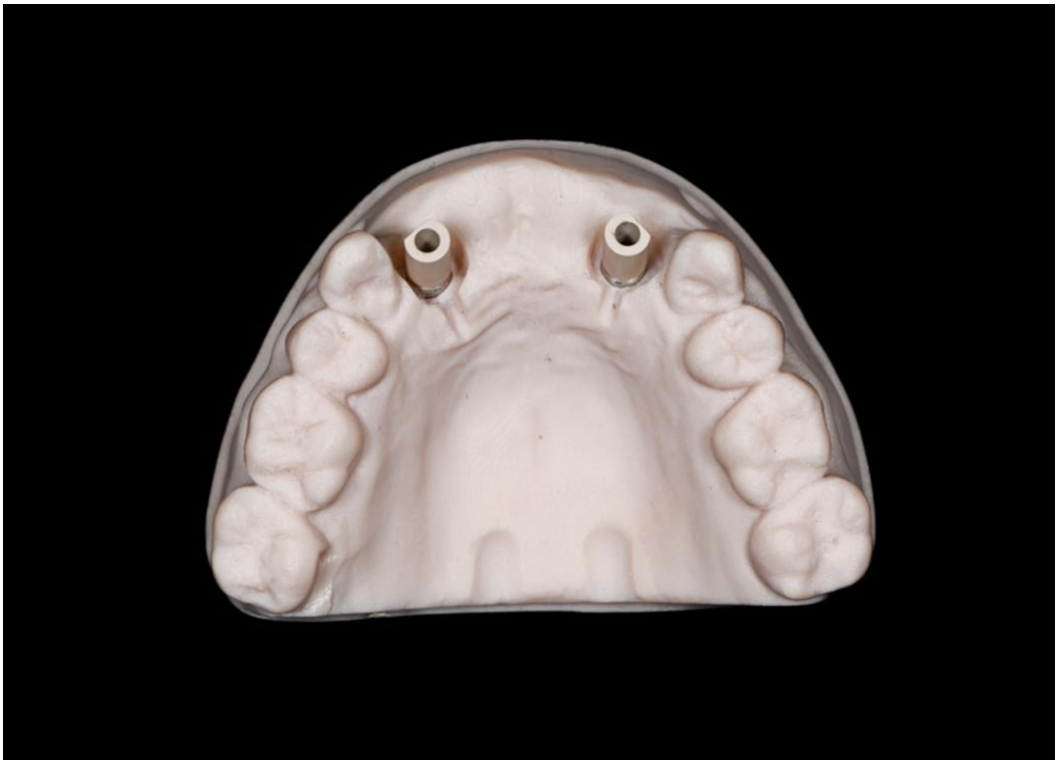

Figure.3: Digital implant impression with scan bodies

Figure.4: 3shape TRIOS4® Intraoral scanner

Figure.5: Milling machine PrograMill PM7 Ivoclar Vivadent®

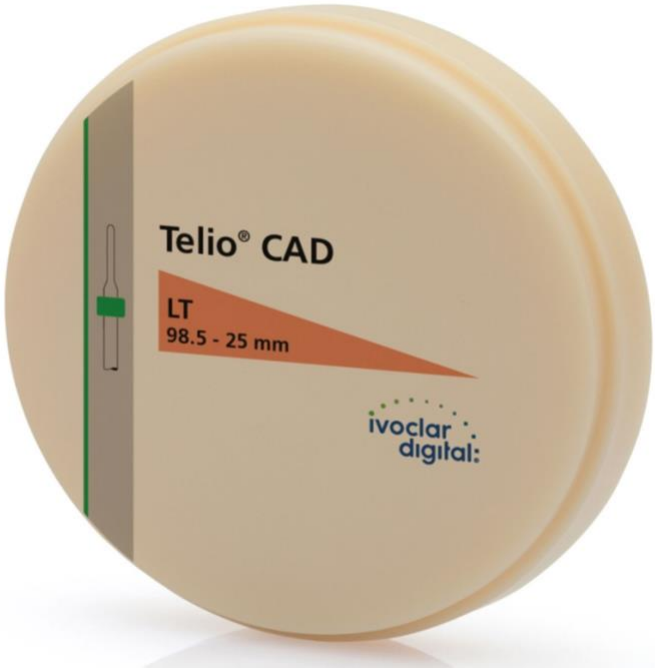

Figure.6: Low translucency LT Telio® CAD PMMA block Ivoclar Vivadent®

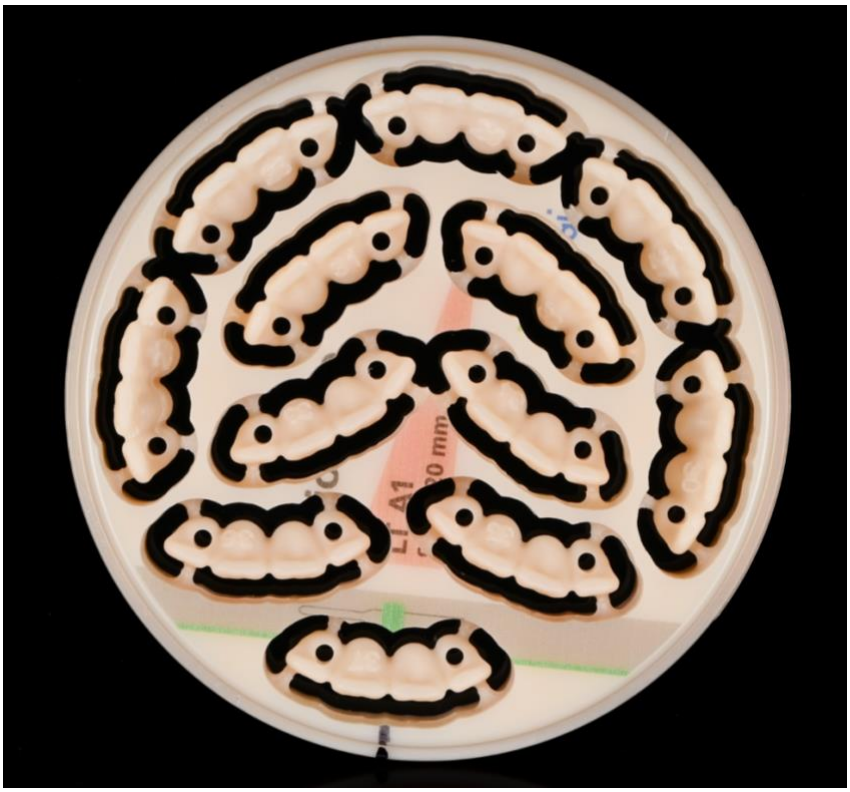

Figure.7: PMMA Prototypes after milling

Figure.8: PMMA prosthesis on the master cast

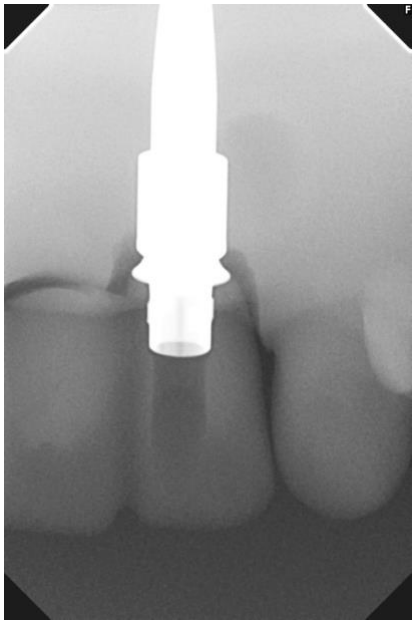

Figure.9: Radiographic evaluation of PMMA prosthesis fit on the master model.