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Faculty of Dentistry
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Evaluation of Digital Versus Conventional Techniques for Construction of Mandibular Implant Retained Overdenture

Thesis

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Dedication

This work is dedicated to the soul of my parents, whose memory sustained me through the hardships of my life may ALLAH *forgive them and always rest in peace*

My wife

My sons

My brothers and my sisters

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List of Abbreviations

Abbreviation	Full Name
3D	Three Dimensional
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CAD	Computer Aided Designing
CAM	Computer Aided Manufacturing
CD	Complete Denture
STL	Standard Tessellation Language
RPT	Rapid Prototyping Technologies
SLA	Stereolithography
2D	Two Dimensional
RPD	Removable partial denture
DLP	Direct Light Processing
DMD	Digital Micro Mirror Device
UV	Ultra Violet
MJ	Material Jetting
PP	Polyjet Printing
ME	Material Extrusion
FDM	Fused Deposition Modeling
SLS	Selective Laser Sintering
SLM	Selective Laser Melting
DMLS	Direct Metal Laser Sintering
CO2	Carbon dioxide
EBM	Electron Beam Melting
CNC	Computer Numeric Controlled
PMMA	Polymethyl methacrylate
ZrO2	Zirconium oxide
Fig.	Figure
CBCT	Cone Beam Computed Tomography
PVS	Polyvinyl siloxane
IPA	Isopropyl alcohol

Abstract

Purpose: To evaluate two implant-retained complete mandibular overdentures construction techniques: Conventional versus Complete digital workflow techniques, regarding occlusal wear, occlusion force distribution and patient satisfaction.

Methods: Six patients were selected for this study from the Prosthetic Department, Faculty of Dentistry, Mansoura University. Each patient received two implants in the mandibular canine areas with locator attachments to retain the overdentures. According to the overdenture construction technique, all patients were randomly divided into two equal groups. ***Group 1*****:** Conventionally constructed overdentures and ***Group 2*****:** Complete digital workflow constructed overdentures. All overdentures were evaluated for occlusal wear using 3D digital analysis, occlusal force distribution using a digital occlusal analysis system (Occlusense) immediately (T0), after 6 months (T6) and after 12 months (T12) of insertion and patient satisfaction after 3 months of overdenture insertion by using patient's questionnaires.

Results: 1- Digitally constructed overdentures showed statistically significant occlusal wear than Conventional overdentures group at T6: incisors ($P \leq 0.001$), molars ($P \leq 0.001$), and at T12: incisors ($P \leq 0.001$), premolars ($P \leq 0.001$), molars ($P \leq 0.001$). 2- Both groups showed statistically insignificant difference of mean occlusal forces at T0 for incisors, premolars, molars ($P \geq 0.05$). At T6, there was statistically significant difference between groups in incisors ($P=0.035$), molars ($P=0.045$), also at T12 there was significant difference between both groups at incisors ($P=0.037$), Premolars ($P \leq 0.004$) and at molars ($P \leq 0.001$). 3- Regarding patient satisfaction, there was a common statistically insignificant difference between groups ($P \leq 0.074$) in general patient's satisfaction parameters. However, conventional overdentures group the patients were significantly satisfied in terms of esthetics ($P=0.001$) and phonetics ($P<0.001$) than digitally constructed overdentures group. On the other hand, digitally constructed overdenture group showed superior patient satisfaction regarding retention and stability during function ($P \leq 0.001$).

Conclusion: Within the limitations of this study, including the patient number and time interval, it could be concluded that: 1- Implant overdentures constructed by conventional techniques maintain the occlusal table after one year of overdenture insertion compared to digitally constructed overdentures. 2- Digitally constructed implant retained overdenture favorably distribute the occlusal force than conventionally constructed overdentures. 3- Implant retained overdenture construction techniques has no impact on patient satisfaction.

Keywords: Implant, 3D-printed Overdenture, Locator Attachment, Occlusense, Superimposition, Occlusal Wear, Occlusal force distribution, Patient satisfaction.

Introduction

For long decades, the traditional approach for treating completely edentulous patients is a conventional complete denture. Regardless the accuracy of the construction procedures including the impression techniques, the jaw relation transfers techniques and the occlusal contact relations concepts, the mandibular denture is often associated with common problems as decreased stability and retention, which affected by the ridge form and other anatomical and physiological obstacles. However, continuous irreversible mandibular alveolar bone loss occurs making the stable dentures ill-fitted.(1)

For the last few decades, different implant treatment options are available for rehabilitation of completely edentulous patient to improve retention and patient comfort with minimal or even elimination of functional undesirable movements of the mandibular overdenture.(2) A 2-implant retained mandibular overdenture could be considered the minimal standard for treatment of completely edentulous mandibular ridge. It was agreed that two implants placed in the anterior mandibular region with attachment systems provide better mechanical retention and stability, as well as greater chewing comfort and patient satisfaction.(3)

It was reported that implant retained mandibular overdentures were found to enhance masticatory function and patient satisfaction. Patients using mandibular implant overdentures can consume tough foods, chew more efficiently.(4) Implant retained/supported overdentures demonstrate superior patient satisfaction rates compared to conventional complete dentures.(5)

The 3D-printed denture uses additive technology to construct a denture following virtual digital design of denture base and teeth from

methacrylate-based photopolymerized resin that is processed and cured by 3D-printing only. This rapid prototyping could be considered as a high accurate alternative to conventional denture construction technique. It allows virtual predesign option to optimize the relation between the implant attachment without weakening the denture base with optimal esthetic outcome.[6]

Obtaining bilateral balance of complete overdenture is the occlusal goal of the prosthodontics.[7] It was established that wear resistance is a crucial physical characteristic of artificial occlusion. It indicates the prosthesis's capacity to uphold the established occlusal relationship, which makes it a significant factor in determining the longevity of dentures. Once the occlusal wear occurs as a result of stresses of mastication during functional and parafunctional movement, the potential for lost occlusal vertical dimension, reduced masticatory efficiency, fatigue of the masticatory muscles, and discomfort for patients must be considered.[8]

The aim of this study was to evaluate two different implant retained mandibular overdenture construction techniques: Conventional versus Complete digital workflow, regarding occlusal wear, occlusal force distribution and patient satisfaction. The null hypothesis was no difference between the two construction techniques could be expected.

Review of literature

Mandibular implant overdenture

Complete dentures have been and continue to be the reliable treatment for edentulous individuals, despite the fact that they cannot be regarded as a replacement for natural teeth. There have been notable developments in the science and art of complete denture prosthodontics within the last century. However, the denture should be adjusted to compensate for the progressive tissue changes brought on by denture use.(9)

Common issues with these prostheses, particularly the lower denture, include reduced stability and retention, which are influenced by the ridge's shape. Over time, alveolar bone loss occurs continually, resulting in poorly fitting dentures.(10)

Because of their decreased load-bearing capacity, poor masticatory action, impaired tongue motor control, decreased bite force, and compromised oral sensory function, patients with significantly resorbed alveolar ridges consistently experience issues with their traditional dentures. Numerous treatment approaches, such as denture adhesives, cushions, and soft liners, have been tried to assist patients who are fully edentulous.(11)

Implant-supported/retained overdentures are now the first line of treatment for the rehabilitation of mandibular full edentulism due to extensive clinical experience and good success rates.(12)

High bone density in the parasymphyseal region is especially important for the long-term clinical efficacy of mandibular implant-supported/retained overdentures because it offers the best initial stability and minimizes implant micro-motion during the tissue healing phase.(13)

According to Meijer et al., endosseous implants, to which an overdenture can be affixed, are frequently used to address issues with the stability and retention of a lower denture.[14] Compared to soft tissue retention offered by dentures or adhesives, mechanical implant retention is significantly superior and results in fewer side effects. Implants allow patients to exert greater bite forces and lessen soft tissue abrasions by stabilizing mandibular dentures when mylohyoid and buccinators muscles contract during speech or mastication and decreasing movement caused by insufficient height and width of the remaining mandibular and maxillary alveolar ridge and incorrect retromylohyoid and sublingual extension of the mandibular denture.[15]

In addition to general satisfaction scores, information was gathered on comfort, stability, aesthetics, general chewing ability, cleaning ability, and speaking ability. Six distinct meal types soft bread, hard cheese, dry sausage, lettuce, raw apple, and carrot were also evaluated by the subjects for ease of chewing. Compared to patients wearing traditional dentures, those wearing mandibular overdentures supported by two osseointegrated implants reported far higher levels of overall happiness, comfort, stability, and ease of chewing. Additionally, implant management greatly improved the ease of chewing foods with varying textures.[16]

According to published research, an overdenture supported by a mandibular implant significantly improves stability, retention, and the patient's maximum biting force, contentment, and quality of life.[17, 18] Because they are linked to a more stable occlusion, patient satisfaction, and comfort, Karkazis et al. confirmed that full prostheses supported by osseointegrated implants in edentulous mandibles have demonstrated a significant improvement in muscular activity and mandibular movements.[19]

Also osseointegrated implants have been demonstrated to enhance mandibular border movements, provide a regular chewing pattern with increased electrical activity of the masseter muscles, and improve oral function.[20] Additionally, they enhance masticatory performance and maximum bite power, enhance patient satisfaction, and reduce masticatory pain.[17] According to Naert et al., the bone beneath an implant-retained overdenture may resorb less than 0.1 mm annually.[21] According to Paul and Roger patients who underwent implant-stabilized mandibular overdenture rehabilitation showed low rates of posterior mandibular ridge resorption, which were not substantially impacted by the prefabricated bar's design either oval straight bars (resilient joint) or parallel-sided bars (rigid joint).[22]

Mandibular bone resorption was considerably decreased by implant-retained mandibular overdentures.[23, 24] The posterior mandibular residual ridge resorption in individuals wearing implant overdentures and those wearing conventional dentures was compared by Kordatzis et al., according to the findings, the conventional denture groups experienced an average decrease in posterior mandibular residual ridge height of 1.63 mm over the course of five years, whereas the implant overdenture group experienced an average reduction of 0.69 mm. Because the remaining posterior ridge is shielded from excessive loading, which is inversely related to the distance from the implant, and because the bone next to the implants experiences less adverse loading, the authors attributed the lower resorption rates with implant retained overdentures.[25]

In addition to having survival rates of at least 90% in the mandible, overdentures offer improved aesthetics in situations of moderate to severe bone loss, enable the insertion of fewer implants in advantageous sites, and exclude areas that are not suitable for implant placement.[26]

Dental implants allow the artificial teeth to be positioned to improve phonetics and aesthetics instead of in the neutral zones specified by conventional denture techniques. The fragility of a traditional denture can affect phonetics. Regardless of the vertical dimension, clicking may result from the flexing of the buccinators and mylohyoid muscles, which push the posterior part of the denture upward. To keep the denture in place, the wearer's tongue is frequently flattened in the back. To stop the mandibular prosthesis from sliding forward, the anterior mandibular muscles of facial expression may be strengthened. These oral adjustments are not necessary because the implant prosthesis is stable and retentive.[27, 28]

Overdenture is any type of removable dental prosthesis that covers and supports on one or more existing natural teeth, the remaining roots, and/or dental implants.[29]

Overdenture prosthesis can be classified as either implant-supported overdenture or as a combination of implant-retained and tissue-supported overdenture. Mucosal support is optimally achieved through hinging movement of the superstructure, utilizing either two solitary anchors or a splinted structure with a round or ovoid bar and a single clip. When there are more than two implants or many bar segments, a rotational axis is absent, and the overdenture is predominantly supported by implants.[30]

Removable implant-supported overdentures

The overdenture that receives support during function may be obtained solely from the implants (mainly implant borne). In this case, the mucosa of the edentulous ridge does not take part in the supporting mechanism. Thus, removable overdentures should be denoted as implant-supported overdentures. Here, removable implant-supported overdentures are usually entirely supported by multiple implants that are rigidly

connected with a bar or a combination of bars, and other individual attachments. Therefore, an adequate number of implants is required.[31, 32]

When implant supported fixed overdentures are difficult to be used as in case of moderate to severe ridge resorption, the implant supported removable overdentures are the best substitute. Overdentures are a viable alternative due to their relatively low cost and are suitable when multiple implants cannot be placed in appropriate positions to support a fixed prosthesis due to anatomical constraints.[33]

Removable implant tissue-supported overdentures

When an overdenture gains its support from both the implant and the tissue, it should be called an implant-tissue-supported overdenture (implant-mucosa borne). In such cases, fewer implants are required. Mucosal tissue provides posterior support for these prostheses, whereas implant superstructures provide retention and anterior support. Removable implant tissue-supported overdentures are attached to the implants, usually in the form of a bar, balls, Locators, magnets or telescopic attachments that permit movement of the overdenture during function and allow the mucosa of the residual ridge to be involved in dissipating the imposed force.[34, 35]

Fixed implant-supported/retained prosthesis

As the name indicates, this type of prosthesis cannot be removed by the patient. It is indicated when the bone volume and quality are adequate to place the required number of implants (usually four or more). When all other factors, such as complexity and costs of such treatment, are considered, the fixed implant-supported prosthesis is a favorable option for many patients.[36]

A fixed-cantilever prosthesis can be used when four implants are placed in the anterior region of the mandible. More implants, which are

well distributed in the anterior and posterior regions of the mandible, can also be used. The fixed implant-supported prosthesis design results in reduction in soft tissue damage and the tissue coverage by the prosthesis is reduced. However, the differences in surgery and costs between the removable and fixed prostheses should be considered when a comparison between the two is made.[35]

Fixed implant-supported prosthesis are of two basic types: hybrid and porcelain-metal. The hybrid prosthesis is made of metal substructure, acrylic and denture teeth. It is indicated when the vertical restorative space is adequate to accommodate the prosthesis, or even increased, as this increase can be filled with acrylic to achieve good aesthetic results. Also, acrylic teeth are more resilient; therefore, they can reduce the impact of occlusal loading. On the other hand, the porcelain-metal fixed prosthesis is made of metal substructure and porcelain in a similar way as that used in the fabrication of the conventional porcelain fused to metal fixed prosthesis. It is more expensive than the hybrid and is difficult to make, but it is a useful option when the vertical restorative space is limited.[22, 37]

Implant overdenture attachments

Attachments are two-component devices utilized for the retention, fixation, and stabilization of prosthesis into position by mechanical locking. They consist of one component that is incorporated into the denture base and called the attachment matrix and the other component that is screwed into the implant fixture and called the attachment patrix.(37)

The retentive attachments for implant-retained/supported overdentures have several types. They may be divided into splinted attachment, as the bar/clips, and non-splinted attachment, as the ball, locators, magnets, and telescopic attachment. Also, they can be also classified according to the range of movement into resilient and non-resilient ones. The resilient attachments permit motion of the prosthesis in six directions: mesial, distal, lingual, facial, gingival, and/or occlusal. They include balls, magnets, telescopes and bars/clips. The non-resilient (rigid) attachments includes U-shaped bars, milled bars, and telescopes.(38)

Splinted attachments (Bar/clips attachments)

Bar attachment makes a rigid connection between abutments, which represent the anchor that retains the denture and gives it support. (39)An element that fits on the bar is usually in the form of a clip (channel or sleeve) that is attached to the fitting surface of the overdenture splinted attachments may have various cross sections as round or egg-shape (resilient joint), and parallel sided U-shape (rigid joint).(40)

The manufacturing bar attachments may be customized made from (Milled plastic) or prefabricated as (Dolder and Hader bar). The bar should be rigid enough to prevent its distortion. The clip may be rigid, as made of gold (Dolder), or resilient made of plastic (Hader).(41)

The CAD/CAM bars are made from a block of commercial pure titanium or titanium alloy. Commonly, the denture is made and the stone cast and wax setup are scanned optically to generate their exact 3D images. The information is sent to the milling machine to form the bar. The CAD/CAM technology reduces certain human errors, therefore, milled bars are usually of high quality and are porosity free.[35]

With bar attachment, retention and stability are improved and less screw loosening and bone resorption occur. Perceived advantage of the bar is that it can accommodate to divergent implants. However individual attachments can also be used for divergent implants.[42] Cases where denture stability is not optimum, as in severely resorbed ridge, using bar attachment can improve the stability better than the use of individual attachment.[41]

Bar attachments also present drawbacks, such as the need for complex laboratory procedures and potential misalignment when multiple implants are used. Research shows that milled bars generally lead to lower maintenance issues and fewer technical complications compared to prefabricated round bars, affirming their effectiveness in clinical settings. Bar attachments play a crucial role in improving the longevity and functionality of implant-supported overdentures.[43]

Non-splinted attachments (solitary, stud attachments)

The most popular attachment systems and the simplest to use are the stud attachments. Stud attachments consisted of a female part which is frictionally retained over the male stud and incorporated into the denture resin either by the means of a transfer coping system and the creation of a master cast incorporating a replica of the attachment or directly in the mouth using self-cured acrylic resin.[44]

Various types are available, representing solitary attachments depending on their characteristics as:

A. Ball and socket attachment system

This attachment system consists of a retentive patrix and matrix. The retentive patrix is part of an abutment and is screwed into the implant assembly while the matrix is attached to the fitting surface of the denture and into which the patrix fits and provides retention by means of spring-action arms or an interchangeable elastic ring (O-ring). The patrix has the shape of small ball with different diameters and is typically made of metal alloy. The matrix can be composed of metal or resilient nylon.[35]

For many years, the most popular type of ball anchors and the simplest to use are one ball attachment system known as the O-ring attachment, a plastic ring is fitted in a groove inside a metal ring or socket, which is housed in the fitting surface of the denture. These attachments offer several advantages including a wide range of movement in six different directions, ease of use in insertion/removal, increase the retention of implant complete and partial overdentures, ease of maintenance of hygiene around the implant, low cost, easily cleansable, minimal chair-side time and ease of replacement of elements if required and great patient satisfaction.[45, 46] However, one of the major disadvantages is that the patrix (ball) violates the vertical restorative space because of its high profile as the patrix is standing over the edentulous ridge. As with most other attachment systems, the ball system loses retention by wear of the matrices and patrices. Ball attachments are not suitable to use when the implants are not parallel (an angulation >15°) as retention is reduced significantly and the need for periodic replacement.[22, 36]

B. Magnetic attachments

Magnetic retention is used to attach removable prostheses to implants. Typically, cylindrical or dome-shaped, these magnets are attached to the fitting surface of the base of the denture. The system includes a ferromagnetic keeper cast to a metal coping screwed over the implant fixture, with the magnet being a neodymium-iron-boron or cobalt-samarium alloy.[47] Despite having lower retention force compared to ball and bar/clip attachments , magnetic attachments are viable for immediate loading in completely edentulous patients needing improved retention and stability of their conventional dentures.[48]

The magnetic attachment is a non-rigid dynamic anchor. The retentive unit permits rotary movement of the denture in one or more directions and/or vertical translational movements. Overdentures retained with magnetic attachments have a low resistance to lateral forces, and the subsequent immediate loss of retention is associated with a lower level of implant moment loading, thereby protecting the implant against unfavorable lateral forces.[49] The desire to use the magnetic retention is related to the simplicity involving minimal time at the chair-side and in the laboratory.[50]

The magnetic attachment system has the advantage that its retentive capacity is not affected by the implant degree of divergence; thus, magnets can retain their attractive force when the implants are not parallel. It also has a low profile. By the use of this system, overdentures are relatively easy to place and remove, which is an advantage for elderly patients or those with a limited ability to tolerate or control removable dentures. The magnets had a low maintenance requirement and high success rate.[51, 52]

In contrast, the disadvantages of magnets are retention and corrosion. However, to protect magnetic alloys against corrosion, proplast

coatings (polytetrafluoroethylene and graphite) are used. Satisfactory results were also achieved by encasing the magnet in a gas-tight, biocompatible, non-magnetizable titanium or stainless steel cover, and the relatively increased initial costs.[53]

C. Telescopic (Double crown) attachments

This type of unsplinted attachment consists of two parts (double crown), a primary coping (patrix), which is attached to the implant, and a secondary coping (matrix), which is contained within the fitting surface of the denture. Telescopic attachments can be classified according to shape (parallel–sided or taperd), and load transfer non-rigid (resilient) or rigid types. Rigid telescopic attachments have a definite end position between the inner and outer copings, using parallel-wall or conical crowns for retention by friction and wedging. In contrast, non-rigid telescopic attachments lack a definite end position, having tiny spaces and additional retention elements to provide retention.[54]

The use of double crown single attachments (telescopic) offers an alternative for stabilizing rigid implant-retained removable prostheses, potentially providing better hygienic peri-implant parameters than connected constructions.[55]

Compared to other unsplinted attachments, telescopic crowns have an advantage of providing adequate prosthesis retention and stability, satisfactory mastication and improved phonetics.[35]

They also prevent dislodgment of the distal extension base away from the ridge and increase horizontal stabilization in mandibles with advanced atrophy.[56] The overdenture self-finding mechanism in telescopic constructions facilitates prosthesis insertion. This is important for geriatric patients with decreased manual dexterity.[57]

In contrast, the disadvantages of telescopic denture fabrication require very complicated clinical and laboratory procedures, and the retentive force between the crowns decreases after a period of use; the poor oral hygiene may lead to the cervical caries; also, technical failures may lead to loss of cementation or the denture base, and follow-up, periodic evaluation, and maintenance are necessary to overcome the problems related to technical failures, cervical caries, and retention.[58]

D. Locator attachment

This type of attachment was introduced in 2001 and became one of the most widely applied resilient attachments. It is used on non-splinted, free-standing implants, it is like a resilient joint, as certain movement can occur in the joint.[36]

The Locator attachment system consists of metallic abutment screwed into the implants (male component) and a metallic cap made of titanium alloy embedded into the fitting surface of the denture (female component), also the locator female can be casted, screwed in, or laser welded to milled bar.[51]

According to the manufacturer (Zest Anchors, Escondido, CA), locator attachment is classified as universal hinge, resilient overdenture attachments for endosseous implants.[59] they are designed to provide correct seating and adequate retention of implant-supported overdentures.[60]

Locator attachments have become widely used and are marketed by most implant companies. It has several advantages over other systems. The locator system has been promoted as an alternative to ball attachments, especially when the inter arch distance or the height of the denture is inadequate for processing ball attachments.[61]

Another characteristic of the locator attachment system (Zest Anchors) is the dual retention mechanism, as it consists of frictional and mechanical retentions. The frictional retention is provided by the nylon patrix head that is slightly oversized compared to its matrix component and the mechanical retention is gained by a shallow undercut on abutment in which the outer margin of attachment is snapped.(62)

The housing nylon replacements are available in two types: 1) Internal and external retention and 2) External retention.(63) Therefore, the patrix, when fully seated in the matrix, engages the outer and inner surface of the matrix part (dual retention). The locator attachment is available in different colors with different retention values and strengths, it is available in different vertical heights, it is having a low-profile height of 2.5 mm, have a diameter of 4.1 mm at their seating surface, it has a self-aligning feature and provides some built in angulations compensation.(51, 52)

Depending on the axial divergence between the implants, dual retention inserts (inner stud and external retention) can be used, or inserts with only external retention can be selected for extended use.(64)

Standard locator components will permit up to 10 degrees of divergence for a single implant and 20 degrees between implants, and the extended-range locator components can accommodate up to 40 degrees of divergence between implants.(65) However, the dual retention characteristic of the locator attachment limits laterals and hinge movements. This design reduces stress on the posterior residual ridge and decreases the need for relining, also repair and replacement are easy and fast.(66)

A locator can be used in implant overdentures with a bar for retention improvement. Three methods, the gold bar casting method, the laser welding method, and the drill and tapping method-are used to manufacture locators bar system.(67)

Compared locator attachment to other solitary attachments' dimensions as follow: locator attachment has (3.17 mm) profile height while ERA (4.85 mm) and O-ring (6.14 mm) so locator has the lowest profile that allow it avoiding complications like over contouring of the prosthesis, increased occlusal vertical dimension, separation of the attachment from the denture and patient dissatisfaction.[68]

E. Equator attachment

Another type of attachment with resilient patrices is the OT-Equator attachment. It combines the simplicity of ball attachments with the variety and easy replacement options of locators. It is considered one of the low-profile attachments, with a smaller diameter, hygiene-friendly construction, and the smallest attachment system available with the least overall dimension.[69]

OT Equator attachments allow for movement up to 8 degrees from the abutment axis without misalignment or retention loss. They are ideal for retaining and stabilizing overdentures and removable partial dentures, especially in cases with space limitations due to their small size. So, the smaller the diameter of the attachment, the better the attachments to be used for implant-supported overdentures in terms of minimizing the stresses to the bone. In contrast, the disadvantages of equator attachments are not recommended for implants with a divergence larger than 30 degrees, as this can cause rapid wear of the retentive caps and result in retention loss.[70]

Factors affecting selection of attachment type

Selection of an attachment system that is suitable for a specific clinical situation is sometimes difficult. A good knowledge of the different systems and their mechanical properties, and the way in which they

distribute load, is important. Some factors that should be identified and considered in order to obtain the best treatment option with the use of removable implant-retained/supported overdentures including:

Quantity and quality of available residual ridge

When the alveolar residual ridge is severely resorbed, a bar attachment and a telescopic attachment provide better horizontal stability, and most occlusal loads are dissipated through the supporting implants. However, the potential risk for mechanical failure of the implant or its components is a concern if an adequate number, size and length of the implants are not appreciated. On the other hand, when bone resorption is minimal, individual attachments such as a Locator, ball or magnet can be used. In this case the denture is mainly tissue supported and the attachments may just be used to retain the denture.[51]

Shape of the dental arch

When the residual alveolar ridge is narrow and has a v-shape, the use of two splinted implants is not recommended because the bar may encroach upon tongue space and interfere with function and speech. If the bar is placed more labially, it may interfere with the lower lip and also affect the denture stability, and may have a negative impact on the aesthetic outcome. Therefore, individual attachments are ideal for such clinical problems when an adequate space between the implants can be granted. Three splinted implants may also provide a good alternative. With three splinted implants, biomechanical risk may be increased, particularly when the implants are short and narrow. In such a situation, the denture should be totally tissue supported whenever possible. A U-shaped residual ridge with adequate bone permits placement of four implants that are connected with three bar segments. However, the inter-implant distances should be wide enough to accommodate the bar and the clips

in order to avoid distortion and unsatisfactory retention. The distance between the most anterior implants and the most posterior implant (anteroposterior spread) dictates the cantilever extension if required.(51)

Angle between implants

There is general agreement that when individual (non-splinted) attachments, such as a ball system, are used, implants should be installed parallel to each other to gain the best retention and to reduce the wear rate of the matrices. If this is not possible, other options such as the use of angled abutments or bars may provide an alternative solution. Furthermore, Locators and magnet attachments may also provide a solution when the implants are not parallel.(51)

Amount of required retention

Bar attachments usually provide more retention than individual attachments. Thus, in patients who require maximum retention, bar attachments may fulfil this requirement and represent the most ideal option. A bar that has multiple segments can be combined with individual attachments in order to maximize the degree of retention, support and stability. Also, a Fixed implant supported overdenture may be an alternative. When a single bar is used with two implants, its length should be between 20 and 22mm to obtain good retention and stability. In this case, one or two clips can be used to gain the optimal retention. When the bar is too short, stability and retention are not achievable. If the bar is too long, it may bend when it is loaded and consequently is distorted and may be broken.(51)

Restorative space

Restorative space is a three-dimensional space that is available to accommodate various parts of the overdenture and its attachment system. This space is surrounded buccolingually by cheek, lips and tongue, and

vertically by the edentulous ridge and the occlusal plane of the prospective overdenture. Therefore, it should be appreciated in vertical and horizontal dimensions. Hence, room for the attachment, the superstructure, the acrylic and the teeth is required. If this room is not available, the outcome is negatively affected and, for example, mechanical failure of the denture is a possibility. The aesthetic requirement of the final restoration (overdenture) is significantly influenced by the available restorative space, as well as by the used attachment system. As an example, when vertical space is limited, the use of a bar attachment may violate the inter-occlusal (free-way) space to accommodate the restoration, which results in an inferior aesthetic outcome of the overdenture, as well as possibly leading to other complications that arise as a result of this error. In such a case the attachments with a low profile are the best option; however, other factors should also be considered. A minimum of 12mm of vertical restorative space from the crest of the ridge to the incisal edge is usually required with the bar system. This distance consists of 4mm for the bar, at least 1mm for the space between the inferior surface of the bar and the ridge, and 7mm for the teeth, the acrylic and the clip. A space between the bar and the tissue is required to facilitate oral hygiene, and reduce the possibility of plaque and calculus deposition. When the Locator attachment is used, a minimum of 8.5mm is required, while the ball attachment requires 10-12mm. The horizontal restorative space in the buccolingual direction should also be considered, and the attachment should be placed on the crest of the ridge to achieve the best biomechanical advantages of the attachment. As well as this, the horizontal space in the mesiodistal direction should also be considered. Thus, a good distance between the adjacent implants, which provides a good biomechanical advantage and facilitates oral hygiene, should be considered.[51]

Treatment costs

Treatment and repair costs should be considered when the treatment plan is made, and the patient should be made aware of these costs. For instance, a bar or telescopic attachment is more expensive when compared with other attachment systems. Furthermore, when bar repair or replacement is required, they cannot be carried out clinically and, therefore, laboratory work will be needed. This is a lengthy and expensive process. Also, the denture will be held for some time and the patient may have to leave without the denture. Also, when an implant tissue-supported overdenture is considered, bone resorption of the tissue-borne regions will continue. Therefore, relining and occlusal adjustments are needed on a regular basis. The cost of treatment and its inter-relationship with other factors should be investigated and considered. However, the treatment cost may compromise and interfere with providing the best treatment option.[51]

Other factors

Factors such as the patient's expectations of the prosthetic, personal choice, and knowledge and skills of the dentist and laboratory technicians, as well as opposing (maxillary) arch, may play a role in the selection of a specific attachment system and type of overdenture. All of these factors are interrelated, and their individual and combined effects should be considered and appreciated when the treatment plan is made.[51]

CAD/CAM technology in prosthodontics

Fabrication of the acrylic denture from heat-cured polymethyl methacrylate by compression molded technique still the most popular choice for clinicians in the dental office. The popularity of this fabrication method in denture construction is gained due to its simplicity, as well as this technique needs only simple processing equipment.(71) Moreover, its low cost, ease of repair, relative higher mechanical properties, low density, and acceptable esthetic favored their popularity over other processing techniques. On the other hand, the processing of the heat polymerized polymethyl methacrylate conventional molded technique may result in a higher percentage of residual monomers which act as a plasticizer and decrease the hardness and rigidity of the material.(72)

The CAD/CAM denture fabrication workflow begins with the digitization of the anatomical information. Then, the denture base and, in most cases, also the occlusion is designed virtually by using computer software (CAD). Following the digital design process, the denture base is milled fully automatized from prefabricated resin blocks (CAM). In most CAD/CAM systems, the milling process produces denture bases with customized sockets for the insertion of the denture teeth according to the digitally designed occlusion. The denture teeth are then manually fixed into the sockets by using methacrylate-based bonding agents.(73)

Recent fabrication methods were introduced in the dental practice such as the (CAD/CAM) digital method. This method enables automated fabrication of 3D denture by the utilization of different materials with different mechanical and physical properties.(74)

With this CAD/CAM technology, only 2 appointments are needed for patients to get their complete dentures. All impressions, jaw relations, occlusal plane orientation, tooth mold and shade selection, and maxillary anterior tooth positioning could be finished in 1 patient visit for the fabrication of complete dentures, saving a lot of time and materials for both patients and/or dentists.[75]

The first attempts at the development of a computer-aided system for designing and fabricating removable CDs were performed by Maeda et al. Since then, many developments have been made for improving the methods of collecting the data and conversion to virtual impressions. It has emerged as a new approach for the design and fabrication of complete dentures.[76, 77]

Han et al. in 2017 explained that removable complete dentures were successfully designed using the computerized software through many steps including generation of 3D digital edentulous models, analysis of models, arrangement of upper and lower artificial teeth, and occlusal records. Artificial dentitions and baseplates were successfully constructed according to the designed complete dentures either by milling "subtractive" or three-dimensional (3D) printing "additive" methods.[72, 78] Bonding artificial dentitions to the underlying baseplates produce the finished complete dentures. The development in the clinical procedures that register the required morphology, the prototype three dimensional artificial teeth arrangement program indicates that CAD programs can be developed when artificial teeth are arranged practically as part of the CAD/CAM complete dentures.[78]

Three components (phases) mainly exist by the use of this system, including a scanner, designing software, and processing devices, which are essential for the fabrication of any restorations.[79]

The second component is the designing phase. After a three dimensional image is captured by the use any of scanning techniques, 3D image processing is finished and the digitized data is designed within the computer followed by the construction programs. Finally, surface smoothing, error elimination and undesirable undercuts were blocked at this stage. Different designs of restorations are done using specific CAD software, which in turn send orders to the CAM unit to fabricate restoration.(78)

The Third and final component is manufacturing phase. This step transforms the digital data of the restoration into a physical product by milling machine with the aid of computer using a high quality diamond (disks or burs) which cut the restoration from ingots. This process is known as "subtractive" method, other method is "additive", e.g. selective laser sintering or rapid prototyping so waste and excess of materials not present. Other systems combined the two techniques "additive and subtractive methods".(78)

Data acquisition system/digital impression (scanner)

Digital impressions show advanced methods that assist the construction of a virtual, computer-generated duplicate of the soft and hard tissues of the oral cavity, by using lasers and other optical scanning machines. With the digital method a high accurate impression data will be captured in minutes, without the need for ordinary impression means that some patients find inopportune and messy. Numerous patients consider digital impressions to be an easier and more comfortable method, in comparison with conventional impression techniques. The impression information is then moved to a computerized workstation that creates restorations, often without the need for stone models.(80)

In the last years, the intraoral scanning has been widely applied in prosthetic dentistry as an alternative to the conventional impression taking.[81, 82] A few methods for the direct capture of edentulous jaws have been introduced, but they do not encompass the functional mucosal reflections.[83]

Some clinical cases have shown the pathway till delivery of the definitive complete denture utilizing intraoral scans in a fully digital workflow either considering no functional borders molding. such technique was reported to provide a denture with sufficient retention, however, major concern here may be the overextension and neglecting of the functional movements.[84]

In general, there are intra oral and extra oral scanners. An intra-oral scanner is a scanning device that is based on the collection of 3-D structures called the "triangulation procedure." Here, the light source with the receptor unit is presented in a specific angle in relationship to each other. With the aid of this angle, 3-D data is calculated by computer from the image on the receptor unit. White light or laser beam can be used as a source of lighting. An example of optical scanners in the dental marketing field is Lava Scan ST, 3M ESPE, scanning source=white light, Everest Scan, KaVo, scanning source=white light, es1, etkon, scanning source=laser beam.[81, 85]

The intra-oral cameras can be divided into two types; single image cameras which records individual images of the dentition. The iTero (Align Technology), PlanScan (Plan- meca), CS 3500 (Carestream Dental LLC), and Trios (3 shape) cameras are single image cameras which record three teeth per single image. In order to record larger areas of the dentition, a series of overlapping individual images are recorded such that software program can assemble these into a larger three-dimensional virtual model. The camera is directed in different angles to make ensure that the recording of data below the height of contour that would be hidden from the camera.

Those areas not visualized by the camera in the overlapping images would then be extrapolated by the software program to fill in the missing data areas in the virtual mode. The other type is real definition scanner video cameras (newest edition of the Lava Chair side Oral Scanner, COS), Apollo DI (Sirona) and OmniCam (Sirona) systems.[86]

The difference between intraoral scanners is that all the cameras can get full arch scan and they can scan implants intraorally except Plan Scan. The Trios, iTero, and True Definition Scanners can perform orthodontic analysis.[87]

Laboratory scanners are classified into (a) optical scanners which use the projection of a measuring light grid onto dental structures under a definite angle causing a depth-dependent phase shift of the grid, which the camera registers on its digital sensor. 3D dental structure data measured by the device from the depth modulated measurement grid image, and (b) mechanical scanners in which the scanner, such as the Nobel Biocare Procera Scanner, is can read a master cast mechanically line by line by means of a ruby ball to obtain 3D measurement.[88]

For type of mechanical scanning devices, the poured cast is mechanically scanned (read) line-by-line by the use of a ruby ball and the object three dimensionally was measured and characterized by a high quality of scanning accuracy. Then, all digital data collection would be designed then milled, this technique is somewhat complicated, more expensive and time consuming compared to other scanner.[89]

Designing software

The restorations are designed using Special designated software called CAD software that is provided by the manufacturers for the design of various 3D dental restorations on computer. The operator enters the data acquired from the scanning process and confirms the features of the

preparation. These data are stored in a special format called standard transformation language (STL). When the designing of the restoration is completed by the software, it is then transformed into virtual model using specific set of commands. Even in the most automated system, the operator has the option to modify the automatically designed restoration to customize it to their requirement. Once the restoration is designed in the CAD, the CAM unit, fabricates the final restoration.[89]

Maeda et al reported the pioneering work to design and fabricate complete dentures using CAD/CAM. They developed a computer-aided system including a work station for determining artificial tooth arrangements, occlusion, the outline of polished surface, and denture border location using a knowledge data base.[90]

Efforts have been made to develop computing programs or CAD software capable of designing complete dentures. However, the progress was slow to extensively exploit this CAD/CAM technology to fabricate complete dentures for edentulous patients due to the complicated construction for complete dentures, which significantly challenged the development of software or computing programs. Recently, some systems of commercial CAD software have been improved to have the capability of designing complete dentures.[90]

The major steps involved are the generation of 3D-digital edentulous models, model analysis (ie, determining the occlusal plane, feature points, and margin lines of denture bases), tooth arrangement, trimming relief areas, fixing local defects, and occlusal adjustment. Software supports the construction of 3D edentulous digital models via 3 scans for maxillary master cast, mandibular master cast, and maxillary occlusal rim with maxillary baseplate and mandibular occlusal rim with mandibular baseplate. The whole process could

be finished within minutes. The length and width of dentitions could be determined after specifying the feature points in mandibular and maxillary arches. The occlusal plane for the dentitions remained the same as the preset occlusal plane, with only some fine tuning needed for minor adjustments. The upper and lower dentitions were correlated, which meant any change on 1 dentition would result in corresponding changes on the other, while maintaining the same occlusal relation. Virtual articulator can dynamically simulate the movement of individual mandibular jaw, and also simulate both static and dynamic occlusal contacts, thus providing more details than the oral and mechanical articulator could provide. It could simulate the occlusion, laterotrusion, pro/retrusion, and side shift through the customized parameter values input for the patients.[90]

Manufacturing processes

The CAD/CAM digital fabrication technique utilizes the fabrication of the denture base by either (3D) printing "additive" methods or milling "subtractive".[85]

A. Additive manufacturing

Additive manufacturing on the other hand is made by layering technique in a step-by-step vertical buildup of the object or restoration. The three dimensional design on the software (CAD) is fragmented into thin slices or layer. Each layer is printed over the other until the object is completed by addition of many layers of the material over each other. The machine needs to lay down 5 to 10 layers of the material to build a one millimeter of the restoration. That is why this technique is called additive manufacturing, rapid prototyping, layered manufacturing, solid freeform fabrication or simply 3D printing.[91, 92]

Additive manufacturing can be achieved through various techniques as stereo lithography, 3D printing by inkjet-based system, selective laser sintering and fused deposition modeling. Many materials can be used with this technology including: metals, ceramics, acrylic resin, composite and wax which enable the construction of both fixed and removable prosthesis.[92]

Types of rapid prototyping technologies (RPT)

1. Stereolithography (SLA):

The SLA technology was conceived by Hullhere the building platform is immersed in a liquid resin that is polymerized by an ultraviolet laser. The laser draws a cross-section of the object to form each layer. After the layer is polymerized, the building platform descends by a distance equal to the layer thickness, allowing uncured resin to cover the previous layer. This process is repeated a number of times until the printed object are built.[93]

Laser based SLA 3D printing uses ultraviolet laser to trace out the cross-sections of the object. The laser is focused using a set of lenses and then reflected off of two motorized scanning mirrors (galvanometer). The scanning mirror directs the precise laser beam at the reservoir of ultraviolet sensitive resin to cure the layer. The depth of cure, which ultimately determines the z-axis resolution, is controlled by the photo initiator and the irradiant exposure conditions (wavelength, power and exposure time/velocity) as well as any dyes, pigments or other added ultraviolet absorbers.[94]

Generally, on the SLA process the layer thickness depends on the model of the printer which could range between 15 to 150 μm with a superficial roughness of approximately 35-40 μm.[95] The wavelength ranges of the ultraviolet light that polymerized the raw material depends on the printer, but it can range from 200 to 500 nm. One advantage of SLA technology is the temperature resistance and freedom of complex

geometries that can print, whereas the main limitation is the necessity of support structures to manufacture objects that consumes additional material and increase the production and post-processing time.[96]

2. Inkjet-based system or Binder Jet Printing or 3D printing:

In this technique, an amount of the raw powder material (polymers or composites or ceramics) is dispensed from a container by a moving piston which is then distributed and compressed on top of a platform by a moving roller. A liquid adhesive (Water, phosphoric acid, citric acid, etc) is then jetted from thermal or piezoelectric printing heads in a 2D pattern onto the powder bonding the powder particles together and forming a layer of the object. This is repeated for the next powder layer and continued to achieve a complete buildup of prototype.[95, 97]

Curodeau et al[97] used 3D printing technology to produce ceramic molds with embedded surface macro textures which were then poured in molten metal to produce orthopedic implants out of high-resistance chromium cobalt alloy.

Mostafaei et al[98] printed RPD frameworks using binder jet process and reported an acceptable fit on the cast. He added that this method may be used to produce mechanically sound complex-shaped structures.

3. Direct Light Processing (DLP):

The DLP additive manufacturing is very similar to SLA technology. The main difference between the SLA and DLP is the light source, where the image is created by arc lamp or by a microscopically small mirror laid out in a matrix on a semiconductor chip, known as a Digital Micro mirror Device (DMD).[96]

Each mirror represents one or more pixels in the projected image. The number of mirrors corresponds to the resolution of the projected image.[99] a vat of liquid photopolymer is exposed to light from a projector under safelight conditions. The DLP projector displays the image of the 3D model onto the liquid photopolymer.

In this system the physical object is pulled up from the liquid resin, rather than down and further into the liquid photo polymeric system. The radiation passes through a UV transparent window; the process is repeated until the 3D object is built.[99, 100]

4. Material Jetting (MJ, PP):

The material jetting technology could be also called Polyjet Printing (PP) where a liquid resin is selectively jetted out of hundreds of nozzles and polymerized with ultraviolet light.[101] The UV-curable polymers are applied only where desired for the virtual design and, since multiple print nozzles can be used, the supporting material is co-deposited. Moreover, different variations in color or building materials with different properties can be designated including the formation or structures with spatially graded properties.[100]

5. Material Extrusion (ME, FDM):

Also called Fused Deposition Modeling (FDM). It is a 3D printing method based on the extrusion of a thermoplastic material, material is drawn through a nozzle, where it is heated and is then deposited layer by layer. The nozzle can move horizontally and a platform moves up and down vertically after each new layer is deposited.[102]

The FDM process has many factors that influence the final model quality but has great potential and viability when these factors are

controlled successfully. Although FDM is similar to all other 3D printing processes, as it builds layer by layer, it varies in the fact that material is added through a nozzle under constant pressure and in a continuous stream. This pressure must be kept steady and at a constant speed to enable accurate results.[103]

Material layers can be bonded by temperature control or through the use of chemical agents. Additionally, the nozzle which deposits material will always have a radius, as it is not possible to make a perfectly square nozzle and this will affect the final quality of the printed object. Accuracy and speed are low when compared to other processes and the quality of the final model is limited to material nozzle thickness. When using the process for components where a high tolerance must be achieved, gravity and surface tension must be accounted for. Typical layer thickness varies from 0.178mm to 0.356mm.[93]

6. Polyjet printing (PP):

A liquid resin is selectively jetted out of hundreds of nozzles and polymerized with UV light. The resin is applied only where desired and the supporting material is co-deposited. A combination of material color and properties can be used within the same object.[94]

In a cross-over study conducted by Inokoshi et al,[104] a try-in denture design was completed using CAD software, manufactured using a poly-jet 3D printer and compared with conventional ones on ten patients. Both techniques were equal for patient ratings, in terms of esthetics, stability, comfort and overall satisfaction; however, for the dentists' rating, they were significantly higher than the conventional method in terms of try-in stability, time factor and overall satisfaction.

7. Selective Laser Sintering(SLS), Selective Laser Melting(SLM), Direct Metal Laser Sintering(DMLS):

In these techniques, the layers are built successively by fusing powder particles using a CO2 laser beam that follow a path on a powder bed based on the desired CAD design. SLM, on the other hand, is based on melting the powder rather than sintering it.[100] Ceramics, polymers, and metals are different materials to be used by SLS, whereas DMLS is used to sinter metal particles.[105]

In addition, SLM as well as SLS are commonly used for the fabrication of RPD frameworks reproducing the fine and complex structure of the framework as designed.[106] Gao et al. reported the use of laser rapid forming technique to fabricate titanium CD bases in a faster and less expensive way compared to conventional method.[107]

The process of SLS can produce implants with complex geometry and a porous surface which increase osseointegration and the implant success rate.[108]

The technique of SLS has significant dental advantages including various materials such as nylon and thermoplastic composites, casting wax, ceramics and metallic material can be used in this method, Cutting chips do not occur, clasps, connectors, and undercut areas can be formed, many frameworks can be simultaneously fabricated, automatic nature of the process and the low cost.[109]

8. Electron beam melting (EBM):

In this technique, an electron beam is used to melt metal powder (stainless steel, titanium, and copper) in a vacuum chamber as controlled by computer laying down successive layers of molten metal to produce mesh-shape or highly porous metal parts. This can be used to produce

customized implants with porous structure allowing bone in growth, providing better fixation, and preventing stress shielding.[110]

B. Subtractive Manufacturing

Subtractive manufacturing is a computerized shaping of a block made from certain material in which a software is used to design the restoration model and translate this design to a computerized machine (CAM) to achieve it.[111]

It is done either by spark erosion or by a milling machine called computer numeric controlled (CNC) machine which utilizes 3 methods for milling. The first method is by utilizing diamond grinding technique, the second method is by carbide milling and the third and most recent is laser milling. The spark erosion is a method in which sparks are generated to remove the material form a metal block. However, the accuracy and fit must be compensated during milling to reach the desired size without any magnifications, shrinkage or distortion in shape.[112]

Milling also depends on dimensional approach and number of working axis. It may be three axis milling, four axis milling or five axis milling.[111, 112] Three-axis milling has a degree movement a path of three axial directions denoted by (X, Y, Z values), three-axis milling machine can also turn the component in 180° in the cycle of milling process. The advantages of this milling device are short time of milling procedure, easily control, less cost compared with other type of milling. Examples of 3three axis devices: "in Lab (Sirona), Lava (3M ESPE), Cercon brain (DeguDent)".[113]

In four-axis milling, the tension bridge can also be turned without any limitation during work makes it easy to control bridge fabrication with

a long displacement in a vertical direction into the usual mold dimension. The main advantage is saving both milling time and used materials, e.g. Zenoo "Wieland-Imes".[114]

For the five-axis milling, in addition to 3,4 axes, new rotatable tension bridge and spindle of milling (5-axis) with complex geometries subsections are presented. This is indicated in the construction of crown and fixed bridge for inclined abutment teeth "when molar tipped towards the medial plane".[115]

Dry field milling is mostly applied to mill ZrO_2 blanks having lower degree of pre-sintering. One of dry milling process recommended by manufacturers is milling a resin material for the construction of different temporary and permanent restorations were designed using CAD/CAM system. Its advantages are low costs are used as a milling procedure and no need for drying of the ZrO_2 frame prior to sintering because there is no moisture absorption by the die ZrO_2 mold. Disadvantages: Higher shrinkage values where obtained for the frameworks are due to the lower degree of pre-sintering.[78]

For wet field milling as a protection, a spray bath of cooling system applied to reduce overheating within the milled material by the use of diamond or carbide burs. This Wet field milling is indicated for all metal-alloys and glass- ceramic to prevent damages by heat generation. When ZrO_2 - ceramic with high degree of pre-sintering lead to minimize the shrinkage factor and less sinter distortion.[78]

Properties of conventional, milled and 3D-printed dentures

Polymethyl methacrylate (PMMA) is the most common material used for fabrication of acrylic dentures, including the denture base and denture teeth, because of its relative ease of processing, biocompatibility, and aesthetic properties.[116] However, PMMA shrinks upon polymerization and its mechanical properties deteriorate over time, which increases the susceptibility of microbial colonisation and lowers the wear resistance. All these shortcomings, coupled with the increased demand for dentures, have led to the advent of digital dentistry.[117]

Few studies assessed the mechanical characteristics of PMMA processed by using CAD/CAM milling and 3D-printing technologies. When compared with 3D-printed complete dentures, the intaglio surface of CAD/CAM milled complete dentures had favorable trueness and mechanical properties.[118] In addition, industrially prefabricated PMMA block for CAD/CAM milling presented a general improvement in material properties compared with heat-polymerized PMMA due to the strict control over pressure and temperature conditions during polymerization.[119] Previous studies demonstrated improved surface properties with PMMA CAD/CAM blocks compared with heat-polymerized PMMA.[120] However, the surface roughness values of all tested denture base materials were below 0.2 μm, which was reported as clinically acceptable.[121] Comparison of surface roughness also with 3D-printed PMMA may be beneficial for clinicians to understand the differences amongst PMMAs fabricated by using varying techniques.[122]

Digitally made dentures are not prone to polymerization shrinkage, thus producing better fitting surfaces, higher chewing effectiveness and potentially removing the need for remounting after processing.[123] Hence,

the digital process has been reported as a more time-efficient and cost-effective option than the conventional prosthesis fabrication.[124]

Despite numerous advantages of digital workflow of denture production, evidence suggests that digitally fabricated denture teeth are more prone to color change from food and beverage consumptions.[114] This may be because of its porous and irregular structures made during the digital production of the materials. Moreover, digitally made denture teeth are manufactured as one unit and from one material (either a PMMA puck or 3D printing resin of a shade of choice), which limits the translucency of the materials, making them monochromatic and therefore less aesthetic. As 3D printing is a relatively recent technology, the available printers and their technical constraints have posed some limitations in manufacturing denture teeth.[125] Color stability or color change of various conventional denture teeth materials after immersion in different solutions has been investigated extensively.[75]

Additive manufacturing and subtractive manufacturing differ significantly in terms of material usage. Additive manufacturing builds denture bases layer by layer, utilizing only the necessary amount of material, making it highly efficient and minimizing waste. In contrast, subtractive manufacturing involves cutting or milling the denture base from a solid block, which leads to significant material waste as excess material is often discarded.[91]

Material properties are also distinct between the two methods. Certain additive manufacturing techniques can produce denture bases with enhanced mechanical properties, such as improved strength and durability, although the layered structure may result in anisotropic properties, where the strength varies depending on the direction of the layers. Subtractive manufacturing,

however, produces consistent material properties throughout the denture base, often resulting in superior strength and durability.[126]

Al-Dwairi et al. demonstrated significant superiority in surface wettability, surface roughness, and surface hardness of milled PMMA than the conventional heat-polymerized PMMA. Similar results regarding the mechanical properties were reported by Srinivasan et al. The authors reported better mechanical performance with the milled PMMA compared with the conventional-heat polymerized PMMA, although both resins showed similar flexural elastic modulus. Also, milled PMMA presented the highest Ultimate Flexural Strength and Flexural modulus compared with heat-polymerized and 3D-printed PMMAs.[122]

Occlusal wear

The occlusal wear is loss of substance on opposing occlusal units or surfaces as the result of attrition or abrasion.[37]

Tooth wear in a dentition can be a result of attrition, erosion or abrasion and is expressed as loss of dental matter. Wear of dental materials is also critical since restorations have to be resistant to structural and form changes, without causing damage to the opposing teeth.[127]

Wear resistance is a crucial physical characteristic of prosthetic teeth. It assesses the prosthesis's capacity to uphold the established occlusal relationship, which makes it a significant factor in determining the longevity of dentures. Along with speech and aesthetics, patients have high expectations for the masticatory effectiveness of their new dentures, which may be hampered by denture tooth wear. Surface loss is typically more noticeable on posterior teeth than on anterior teeth. Denture teeth wear over time as a result of stresses of mastication during functional and parafunctional movement leading to the potential for lost occlusal vertical dimension, reduced masticatory efficiency, fatigue of the masticatory muscles, discomfort for patients and aesthetic concerns.[8]

Over the past few years, various qualitative and quantitative methods have been suggested to measure tooth wear. Conventional approaches, such as those of Eccles, Smith and Knight, the New Tooth Wear Index (NTWI), or the Basic Erosive Wear Examination (BEWE) assess dental material loss qualitatively through the use of indices. The main shortcoming of such indices is that they are subjective and their sensitivity is unsatisfactory, especially when tooth wear is assessed in relatively short time-spans.[128]

For this reason, quantitative methods on 3D dental models have been developed.[129] These are considered advantageous, since they are more objective and they provide more accurate estimation of the outcome, usually as tooth height or volume loss.[130] However, the utilization of such methods in vivo or ex vivo is usually rather complicated and time-consuming, and thus not feasible in a regular clinical basis or even for research purposes, if the required expertise and special equipment are not available.[130]

The steadily increasing usage of intraoral scanners in contemporary clinical dentistry could provide the required surface models for quantitative 3D wear assessment and the available software in the market could facilitate the ex vivo implementation of the relevant techniques on a regular clinical setting. Previous ex vivo wear assessment methods relied mostly on superimposition of tooth areas that were not considered to be affected by tooth wear between two or more time points. However, the selection of such areas and the validation of these methods compared to a gold standard measurement, which would provide the true value, has not been adequately investigated.[130]

Numerous factors can influence wear assessment through these techniques, such as movement of teeth between two time points, the accuracy of the obtained 3D surface model, especially in areas that are inherently difficult to scan, the reference areas selected to register the serial surface models and the software settings used for the superimposition.[127]

Digital occlusal analysis

According to the Glossary of Prosthodontics, occlusion is a static relationship between the incisal and/or occlusal surfaces of the maxillary and mandibular teeth. It should be balanced and tension-free as far as possible. To obtain ideal occlusion, there must be contact of all the posterior teeth simultaneously and the occlusal forces must be evenly distributed.(131)

Inappropriate contact or an occlusal interference may occur following prosthetic procedures; these destructive forces may then lead to negative effects on masticatory muscles and the temporomandibular joint. To avoid potentially negative effects from prosthetic applications, evaluation and accurate occlusal analysis is important for clinicians to achieve appropriate occlusal contacts.(131)

The occlusal contacts and bite force of a patient provide information for diagnosis and prognosis. Moreover, the number of occlusal contacts and occlusal contact areas are related to chewing efficacy.(132) Thus, it is essential to accurately locate the occlusal contacts on restorations, both in the clinic and in the laboratory. In addition, occlusal contacts should be evaluated to find the occlusal interference during occlusal adjustment.(133)

The occlusal analysis methods used can be separated into two groups as conventional and digital. The conventional methods include articulating paper, silk strips, metal plate, occlusal spray, trans-illumination, early contact indicators, and occlusal sonography. Digital methods include the photo-occlusal system and the T-Scan occlusal analysis system.(131)

Articulating papers or foils used by clinicians to identify the occlusal contacts. However, the number of contacts varies largely depending on the recording method.(134) Moreover, reproducibility of these occlusal

indicators is unreliable.[135, 136] For example, false positive marks are often seen when articulating papers are used, and marks from the articulating paper can be interpreted subjectively. Furthermore, contact marks from articulating papers or foils do not indicate the occlusal force, but only the location of the contacts.[137]

When utilizing articulating paper, the identification of premature contact is determined by the subjective perception of the intensity, shape, and size of the markings. Recently, the T-Scan devices have been implemented for digital occlusal analysis to assess several occlusion parameters, such as the distribution patterns of occlusal force in CDs. The T-Scan provides crucial data on the distribution of occlusal force, which is essential for generating a balanced and measurable occlusal force. Ideally, the occlusal force should be evenly distributed, roughly 50% on the right and 50% on the left sides. This equitable distribution of force enhances the CDs' ability to adapt to the surrounding tissue while chewing.[138]

Is an attempt to bring better care to patients by being able to “see” data that analogue methods and non-digital techniques cannot provide. Two such diagnostic products exist in the market today. The goals are to help dentists make sense of Occlusion. Both the T-Scan 10 System (T-Scan software version 10, Tekscan, Inc., S.Boston, MA, USA) and Occlusense (Dr. Jean Bausch GmbH & Co. KG, Koln, Germany) are digital occlusal analysis systems.[139]

T-Scan 10 system

T-Scan is a computerized occlusal force analysis device. It is an essential part of clinical functional analyses in prosthetic and restorative insertions. The T-Scan computerized system can rapidly determine prematurity, high points, regions of excessive force and non-uniform force

concentration. It can also analyze dis occlusion time accurately. The evolution of pressure sensitive ink-Mylar encased sensor technology, was introduced with the T-Scan I computerized occlusal analysis system by Maness et al. in 1984.[140]

The system components include a sensor and support, a handle assembly, the system unit, computer software and a printer. The T-Scan permits the quantification of occlusal contact data by registering parameters such as bite length as well as the timing and force of tooth contact, and stores the data on a hard drive which can be played incrementally for data analysis in a time-based video.[141]

The recording handle with the sensor and arch support is placed between the maxillary central incisors of the patient. The recording is initiated by pressing the button on the recording handle. The patient is asked to close the mouth till complete intercuspation is reached, without making any excursive movements. For this, the sensor is inserted into the patient's mouth in such a way as to make its support aligned centrally with the midline of the upper incisors. The patient is then asked to bite on the sensor in a maximum intercuspation position. After the handle button is pressed the arch model is automatically created on the screen. It should be taken into account that this model is an approximation of the patient's arch and therefore uncertainty exists as to the exact location of the contact on the screen.[142] The data recorded is shown as a force film, in which the center of force trajectory shows the history of the path of the center of the force from the beginning of the force movie recording to the current displayed frame.[143]

Occlusense system

In September 2019, Digital Future of Dentistry Technology Expo organized at the ADA FDI World Dental Congress in San Francisco

selected Bausch's Occlusense as a winner of the Best of Class (BOC) technology awards in the Emerging Technologies category. Compared to the well-known T-Scan (Tekscan, Inc., South Boston, MA 02127, USA) whose pressure sensor is 100 microns, the Occlusense sensor is very flexible at only 60 microns, permits the recording of both the static and the dynamic occlusion and is additionally covered in red marks the occlusal contacts on the patient's teeth. The technologically advanced Occlusense pressure sensors allow the recording of the masticatory forces in 256 pressure levels. The data can be displayed graphically 2- and 3-dimensional, including the distribution of the masticatory forces recorded digitally. The Occlusense System can be used in various fields of dentistry, including functional diagnostics, dental technology and osteopathy.[139]

Performance capabilities of Occlusense

Occlusense reports 256 levels of force with a 4-color coded scheme (green/yellow/orange/red). This color gradient implies masticatory force distribution in the area evaluated. Also, relative pressure differences between pressure points are indicated by the height of the pixels. The color and height of the pixels indicate relative difference in contacts to adjacent contacts.[139]

No publications on clinical accuracy or effectiveness exist to date. Practicing Digital Occlusion by using data to isolate problem occlusal contacts is very different from practicing Subjective Interpretation, which uses ink marking materials and subjectivity to isolate occlusal contacts.[144] Despite that marking ink sits on the Occlusense sensor, Occlusense's generated digital datasets must be first understood to determine how its digital occlusal data can be used clinically, absent of what its ink markings appear like on teeth. Of note is that nowhere in the Occlusense product

manual, is it explained how to use Occlusense data to improve a problem occlusal condition.[141]

Recording capabilities of Occlusense

A definitive drawback of Occlusense is that although a dentist can live-preview a recording on the App screen, the live preview data cannot be recorded. The actual Occlusense recordings cannot be viewed as they occur in real-time, to see if the patient moved correctly while the recording was being made, or if the data gathered from the patient was well or poorly recorded. And, before a recording can be played back to determine it was a useful data set, the handle must process and transmit the recording to the App, which manipulates the pressure gradient data to fit the Occlusense standardized dental arch outline (which has no individual tooth delineations). This lack of real-time recording means chair time must be utilized to find out if a recording can be used to analyze the occlusion, or if another recording is needed.[139]

Playback capabilities of Occlusense

The recorded Occlusense data is software-sized to fit within the standardized arch form that has no specific tooth delineations. The Occlusense arch cannot be altered to match the patient presentation.[139]

Occlusense force tools

Occlusense uses its various App desktop displays to present the recorded occlusal pressure distribution to the dentist. The App desktop has both a 2D Force Snapshot view and a rotating 3D columnar view (very much like the T-Scan desktop), however the Occlusense 2D dental arch has no distinct individual tooth delineations that are correctible to match the patients true arch.[139]

Relative pressure gradients (manufacturer's term from the Occlusense manual) are depicted in the 2D Force Snapshot window by neighboring green, yellow, orange, and red colored data blocks, that change in color as the pressure distribution changes in different areas of the arch. Small surface area contacts (pinpoint contact) are denoted by orange and red, whereas large surface area contacts (broad contact) are denoted by green and yellow. In the 3D rotational window, the same colored blocks are represented as columns with differing heights. With the Occlusense 4-color scheme describing 256 force levels, the force jumps from color-to-color are large, at 64 force levels/color.[139]

The Occlusense App desktop has both a 2D Force Snapshot view and a rotating 3D Columnar view. In the 2D view, neighboring relative pressure gradients are illustrated by green, yellow, orange and red colored data blocks. Their matching variable height columns are located also on the arch model in the 3D view. The force distribution can be presented to the dentist as an estimated force stock arch tooth. This display segments the perimeter of the stock arch, and then calculates the force percentage located in each segment. Because the stock arch is not matched to the patient's true anatomical dental arch, this display option can only estimate the force % per tooth. The 2D desktop can be segmented to estimate force % per stock dental arch tooth. And the sensor can be quartered into areas of relative pressure. The most pressure in this scan is the posterior left quadrant (solid red background), while the 3 other quadrants are comprised of similar pressure (solid green background). Quartering the sensor, displays behind the Occlusense arch solid-colored regions of red (most pressure in quadrant), yellow (medium pressure in quadrant), and green (lowest pressure in quadrant), thereby grading each quarter's force distribution. The most pressure is distributed in the posterior left quarter (solid red

background), while the 3 other quarters all demonstrate similar amounts of pressure (solid green background).[139]

Time quantification tools of Occlusense

Occlusense does not have and timing tools or time quantification capabilities. Occlusense however, does record dynamically the temporal sequence of intercuspation, which can be played back continuously, or incrementally frame-by- frame, forwards and backwards. There is a Time Bar placed above the playback buttons, which shows playback progress of the patient's occlusal video. Occlusense has no ability to qualify the physiologic health of the time-duration required by a patient to complete their temporal sequence of intercuspation. Absent is the quantification of key Time-Regions that occur during a functional mandibular movement. Therefore, no OT or DT can be determined without the dentist performing a manual calculation, by playing back a recording and marking the distance between certain time- points.[139]

Raw data output possible for research of Occlusense

Occlusense recordings can be exported using iTunes as a video file, and as images in .png format, or as a pdf files. But the saved files can only be played within the iPad App. And unfortunately, Occlusense raw sensor electrical data cannot be exported for study or research.[145]

Patient satisfaction

Polymethyl methacrylate (PMMA) has been used in most cases for the fabrication of conventional complete dentures. The increased acceptance of this material by patients can be attributed to its biocompatibility, aesthetic qualities, and simplicity of processing and repair.[146]

Implant-retained or implant-supported dentures has been documented to increase masticatory function, maximum bite force, nutritional status of patients, speech and patient satisfaction.[5, 146] This is presumably due to the improved retention and stability of the implant supported prostheses. Therefore, rehabilitation with implant-retained/supported overdentures has greatly enhanced retention and masticatory efficiency, decreased pain during mastication and enabled improved utilization of masticatory muscles, enabling patients to consume tough of foods.[4]

The color stability of denture teeth is one of the most important and clinically relevant optical properties of dental materials since color change indicates aging or deterioration of material. Moreover, the color changes affect the overall aesthetics of a prosthesis, affecting patient satisfaction of a removable prosthesis and long-term quality of life. Furthermore, translucency affects the natural appearance of artificial teeth. Natural human teeth are fluorescent; therefore, it is important for denture teeth to achieve fluorescence for a realistic outcome.[147]

The digital fabrication methods for implant denture prosthetics are reduced in laboratory and clinical costs, less frequent appointments required, and a lower overall burden on older, edentulous patients.[148]

3D-printed implant overdentures showed promising results regarding chewing efficiency and patient satisfaction compared to conventionally fabricated implant overdentures. 3D-printed implant overdentures could be a viable option for patients with less aesthetic concerns.[146]

To meet patient satisfaction, dental clinicians need to focus on each patient's expectations and opinion regarding the use of denture, including the comfort level, esthetic appearance, function, and speech.[149] Pera et al. showed that degree of satisfaction was not solely correlated with the masticatory and oral function. They concluded that satisfaction was a highly complex parameter influenced by a number of factors, not strictly related to the stomatognathic system. Hence, one of the most important elements in treatment planning for edentulous patients is to take a detailed history by asking questions regarding the level of masticatory function and the impact of the existing dentures on the quality of life.

The questions of the questionnaire used for assessing patient satisfaction with mandibular implant-supported overdenture as problems with pronunciation of some words, instability during speaking, difficulty during opening, interference during eating or speaking, Change in sense of taste, pain or discomfort when using denture, pain or discomfort when eating by using denture, food impaction under denture, sense of mouth fullness, instability during eating, difficulty in swallowing liquids,change in appearance with denture and denture is not as expected.[5]

Aim of the study

This study was conducted to evaluate two different construction techniques, Conventional versus Complete digital workflow of two implant-retained complete mandibular overdentures regarding occlusal wear occlusion, force distribution and patient satisfaction.

Methods of evaluations were:

1- The occlusal wear was measured by using 3D digital analysis.
2- The force distribution was measured by using the digital occlusal analysis system (Occlusense).
3- The patient's satisfaction was evaluated after 3 months of overdenture insertion by using patient's questionnaires.

The occlusal wear and force distribution were measured immediately (T0), after 6 months (T6), and after 12 months (T12) of overdenture insertion.

Materials and Methods

I. Patient selection

Six completely edentulous healthy patients were selected for this study from the Prosthetic Department, Faculty of Dentistry, Mansoura University. The patients were fully informed about the purpose and the surgical and prosthodontic procedures of this study. Written consents of the ethical committee of Mansoura University dental research [No. A02060922] were signed by the participants according to the following criteria:

Inclusion criteria

- Completely healthy edentulous maxillary and mandibular ridges**. (Fig. 1)**
- The residual alveolar ridges covered with relatively firm mucosa without any remaining roots or residual bone pathology verified by digital panoramic x-ray.
- Sufficient residual alveolar bone quantity (length and width) and quality anterior to the mental foramen of mandibular bone (D2 and D3) according to Lekholm and Zarb to receive suitable size of standard implant. This was verified by using cone-beam computed tomography technology (CBCT) for each patient. **(Fig. 2)**
- Maxillomandibular angel's class I relationship with sufficient mandibular restorative space and interarch space, this was detected by tentative jaw relation record.

Exclusion criteria

1- Absolute Contraindications:

- Patients with systemic issues as recent myocardial infarction, radiotherapy, hepatic patients or bleeding disorders.

- Patients with autoimmune disease like rheumatoid arthritis, recent organ transplant and long term corticosteroid.
- Uncooperative patients or psychiatric disorder.
- Patients with severe osteoporosis or cancer.

2- Relative Contraindications:

- Heavy smokers, unless stopping smoking 2 months before surgery, metabolic disorders that affect osseointegration such as hyperparathyroidism.
- Uncontrolled diabetes mellitus (glycated hemoglobin more than 7%.).
- Carelessness and uncooperative patient specially those not responding to instructions, treatment recalls and hygiene measures.

II. Construction of complete dentures

For all patients, conventional maxillary and mandibular complete dentures were constructed as follows:

- Maxillary and mandibular preliminary impressions were recorded by using irreversible hydrocolloid impression material* and poured in dental stone** to construct primary casts.
- Custom impression trays of auto-polymerized acrylic resin*** were constructed, border molded with green sticks low fusing compound**** to record final impression using zinc oxide eugenol free impression material.*****

* Alginate, normal set impression material, Cavex. Netherlands.
** Dental stone, Elite Model, Zhermack, Italy.
*** Acrostone cold curing acrylic resin, Egypt.
**** Low fusing MAARC green tracing sticks compound, India.
***** Cavex outline, Cavex Co., Netherlands.

- Auto-polymerized acrylic resin record bases were constructed to record maxillomandibular relations.
- The maxillary cast was mounted to a semi-adjustable articulator* using maxillary face-bow** and the mandibular cast was mounted using centric interocclusal wax wafer method.
- Acrylic resin artificial teeth*** were arranged for balanced lingualized occlusal scheme, followed by intraoral try-in after wax up procedures.
- After flasking, the waxed-up trial denture bases were processed into heat cured acrylic resin.****
- After clinical remounting, the occlusal contact was planned for even harmonious occlusal contacts.
- Delivery was done, and the patients were instructed for proper hygiene and periodic recall for any necessary re-adjustment of occlusal contacts after denture settling. **(Fig. 3)**

* Whipmix semi a djustable articulator, USA.
** Whipmix face bow, USA.
*** Acrostone sheet acrylic teeth, Egypt.
**** Acrostone pink heat cure acrylic resin, Egypt.

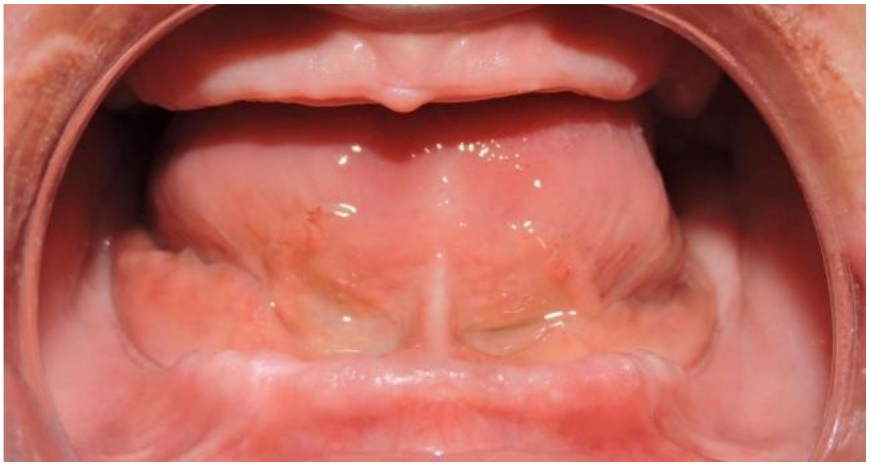

Fig. (1): Completely edentulous patient with firm healthy mucosa

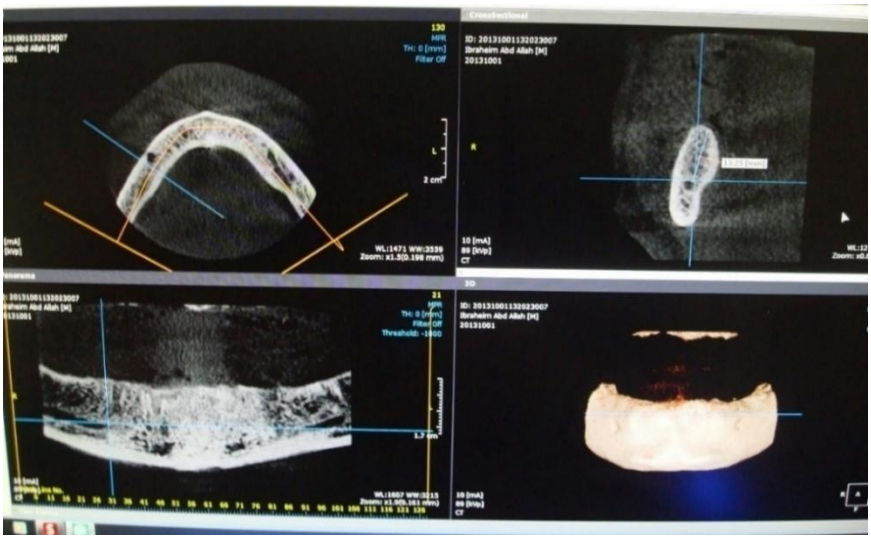

Fig. (2): CBCT was made to confirm sufficient bone quantity and quality to receive dental implants

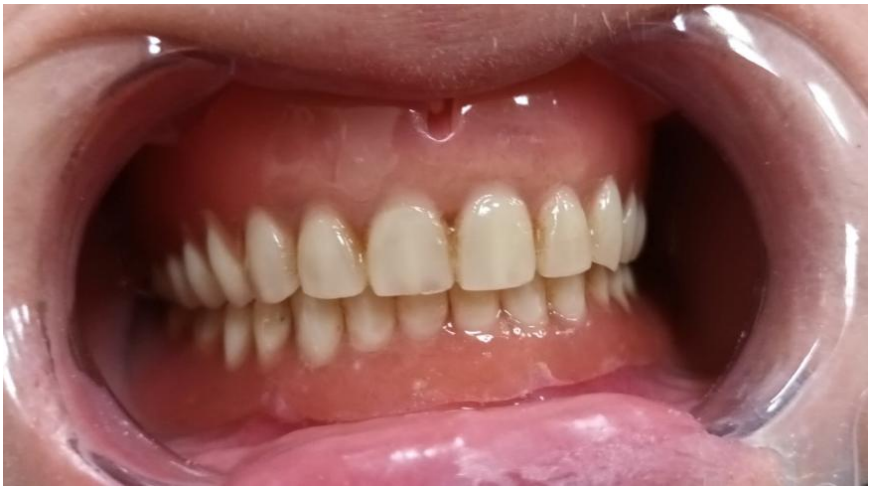

Fig. (3): Conventional complete denture inserted intra-orally

III. Surgical procedures

Pre-surgical stage

- Antibiotic prophylaxis (Clavulanic acid with amoxicillin - 1gm)* was prescribed to each patient one hour before surgery and continued to (5-7) days (twice a day) after surgery.
- All patients were asked to rinse their mouth with antiseptic mouth wash** (0.12% or 0.2%) for 1 minute prior to the surgery and post-operative.
- All patients received two implant fixtures (BTK dental Implant)*** in the canine regions by using BTK surgical kit (ISKONE, BT SAFE, BT NANO & IS+).****

First surgical stage

Flapless surgical protocol was followed to install two implants in the canine areas as follows:

- Circular tissue punch was cut corresponding to the target implant position.
- The initial point of drilling was marked by sharp lance drill (2.00 mm diameter) at speed of 800 rpm.
- Bone drilling was accomplished by the first twist drill (2.00 mm diameter), then the second drill (2.50 mm diameter) and then the third drill (3.10 mm diameter) followed by the final drill (3.45 mm diameter) at (12 mm length) by using drill stops.

* Augmenten 1gm, Octoberpharma, Egypt.
** Vex mouthwash menthol Macro group.
*** BTK dental Implanting trust, smile again, Italia.
**** BTK dental Implanting trust, smile again, Italia.

- Finally, the countersink drill (3.7mm diameter) was used to enlarge the crestal area of the implant site in the area of dense cortical bone to ensure passive fit of the implant neck into the surgical site.
- Drilling was accomplished by intermittent drilling, low speed high torque hand piece and external irrigation to avoid overheating.
- Irrigation was done with sterile saline to remove any debris at the implant surgical site then the closed cap was removed from the fixture implant vial and the fixture driver was inserted into the implant with slight pressure.
- The implant was carefully screwed into the osteotomy by finger until resist screwing, then torque wrench was used to driven the fixture to the final position just below the crest level at 35 N/cm insertion torque.
- Implant fixture was then covered by the cover screw using the screw driver. **(Fig. 4)**

Post-surgical procedures

- Post-operative panoramic x-ray film was made to verify the position and orientation of implants. **(Fig. 5)**
- Post-operative medications including anti-inflammatory* and analgesics** to relieve pain were prescribed for (5-7) days.
- Mouth wash*** was also prescribed for two weeks three times a day.
- The patients were instructed not to wear their dentures for 10 days.
- After two weeks, the mandibular denture was fitted to the mandibular ridge with relief over the implant site to avoid loading the implants, and

* Alphintern, Amon pharma co, Egypt.
** Bi-profenid, Sanofi Avntis, Egypt.
*** Vex mouthwash menthol Macro group.

relined with auto-polymerized silicon soft liner* while the patient close against the maxillary denture until complete polymerization.

- The excess was trimmed and the patient instructed for denture cleaning and follow up recalls.

Second surgical stage

- After the 3 months of osseointegration period, the cover screw location was inspected with sterile probe by penetrating the mucosal thickness at the canine area. Two circular incisions were made at the cover screw area using the tissue punch.

- Cover screws replaced by the healing abutments** (diameter 4mm and height 3mm) to allow healing of peri-implant tissue for two weeks.

* Acrostone, soft relining material, Egypt.

** BTK dental implanting trust, smile again, Italia.

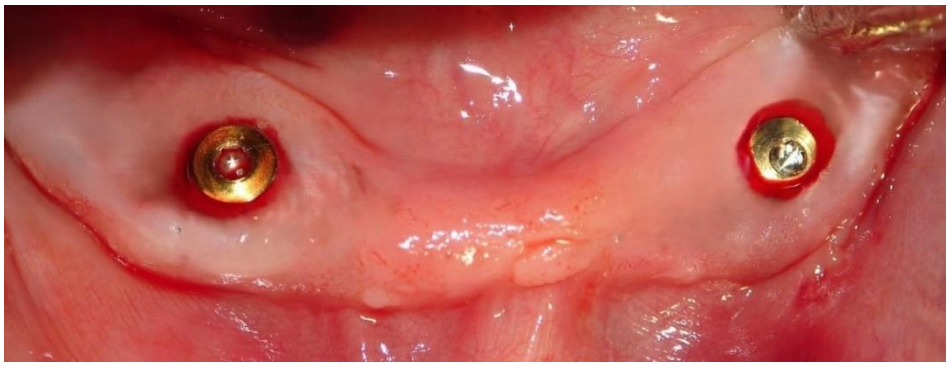

Fig. (4): Implants inserted in canine areas

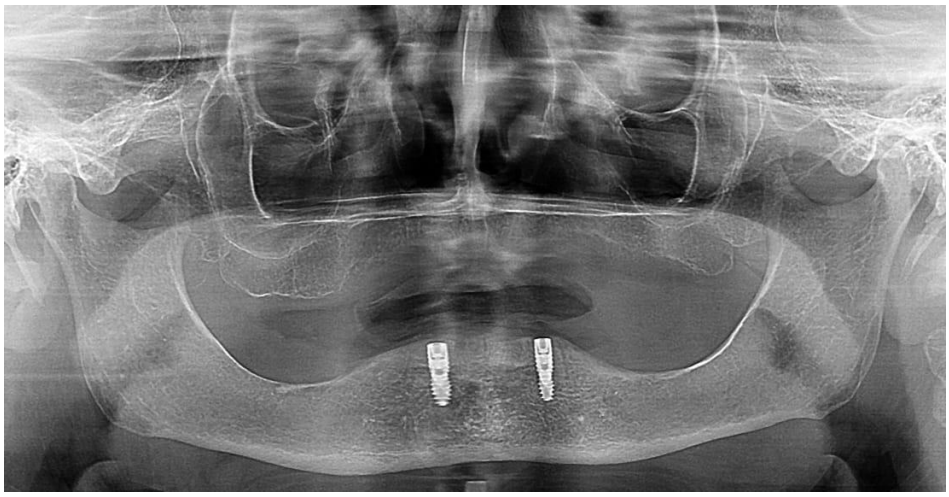

Fig. (5): Panoramic x-ray after implant insertion

Final mandibular overdenture construction

According to the construction technique of the mandibular overdentures, the patients were randomly divided into two equal groups as follows:

Group 1: Received Conventionally constructed overdenture

- The healing abutments were replaced by locator abutments attachment*
- (2.5mm diameter and 4mm height) using the locator screw driver and tightened by the torque wrench 30 N/cm. **(Fig. 6)**
- White locator blocking rings with center hole was fitted around the locator abutment in the gingival region to block the undercut. The metal housings with the black lab processing insert were directly fitted over the locator abutments.
- The fitting surface of the mandibular denture was prepared opposite to the under surface of each canine to create two holes of sufficient size slightly wide than the width and deep than the height of the attachment assembly.
- The prepared denture was tried to fit completely free against the attachment assembly. At least 1 mm. was allowed between the denture and the attachment assembly.
- Lingual venting hole was drilled lingually apposite to each attachment house to allow exit for excess of acrylic resin.
- The mandibular denture was tried in the patient mouth for complete free seating in centric relation against the maxillary denture.
- The attachment houses in the mandibular denture were packed with pink auto-polymerized acrylic resin and the denture was fitted over the

* BTK dental implanting trust, smile again, Italia.

attachment assembly and the patient was asked to close against the maxillary denture until complete polymerization to functionally pick-up the retentive house of the locator attachment.

- The excess resin was trimmed away, the denture was polished and delivered in the patient mouth. The black processing inserts were replaced by pink nylon inserts of moderate retention values by the aid of the insertion tool.
- The patient was trained for atraumatic insertion and removal of the overdenture and to follow hygiene measures specially for the attachment components.
- The patients were instructed for regular recalls for necessary adjustments and evaluation measurements.

Group 2: Construction of 3D-printed complete overdentures

Generation of 3D digital edentulous master cast

- After removal of the healing abutment and screwing the locator attachment into the implants, maxillary and mandibular final impression were recorded as mentioned in the construction of conventional complete denture.
- The maxillary and mandibular master stone casts were constructed and fixed on the extraoral scanner table and scanned by using High Resolution (smart optics) scanner* with modern high-performance camera and blue light LED directed over the cast to scan it in three dimensions, after being lightly coated with anti-glare spray** to produce a virtual master cast and it was saved as standard tessellation language (STL). **(Fig. 7)**

* REITEL. AnySCAN VINYL HR Germany.
** SHERA Werkstoff-Technologie GmbH & Co. KG Germany.

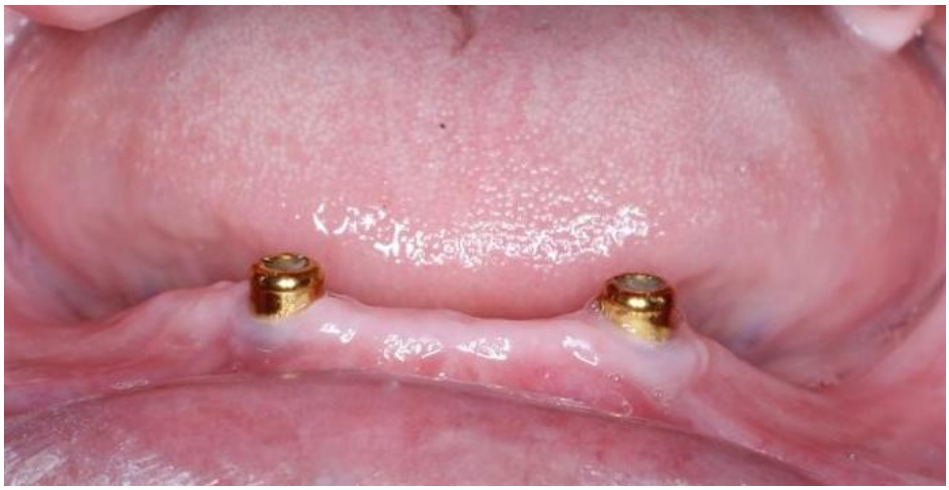

Fig. (6): Locator attachments screwed to implants

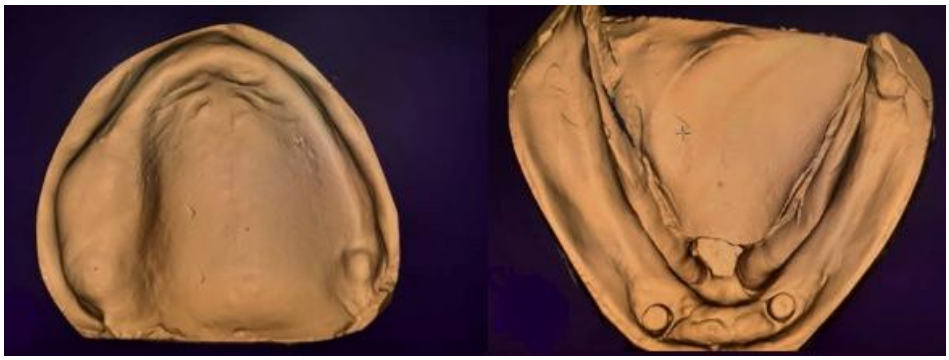

Fig. (7): Scanned master casts with locator attachment and metal housing in place

Designing and printing of the record bases

- The virtual master casts (STL) file was opened with dental design software* to design the virtual record bases, which the anatomic landmarks were identified and the peripheral limits were marked on a virtual master casts. **(Fig. 8)**
- The virtual record bases were designed with uniform thickness greater than 2 mm extended to the vestibule area, then it was separated from virtual master casts and oriented at a slight angle, in which the fitting surface away from the build platform and supporting structures were generated around the perimeter of the virtual record bases.
- The tank of 3D printer** was filled with liquid temporary resin material*** then printer door was closed, the designed virtual record bases file was then exported to software of printer, afterwards printing was started.
- After complete printing, the record bases were removed from the build platform and supports were removed, the finishing and polished of the printed record bases were done by conventional method. **(Fig. 9)**
- Then evaluation of adaptation and retention of the printed record bases were verified clinically in the patient mouth.

Fabrication of record blocks

- Occlusal wax rims were constructed on maxillary and mandibular printed record bases.
- In the patient mouth, the occlusal plane and occlusal vertical dimension were recorded and the reference lines (midline, canine lines and smile line) were marked on the record blocks, centric and eccentric maxillo-mandibular jaw relation was registered. **(Fig. 10)**

* Exocad GmbH, Darmstadt, Germany.
** EPAX 3D 4K 6.6" printer, USA.
*** EPAX 3D temporary printing resin.China.

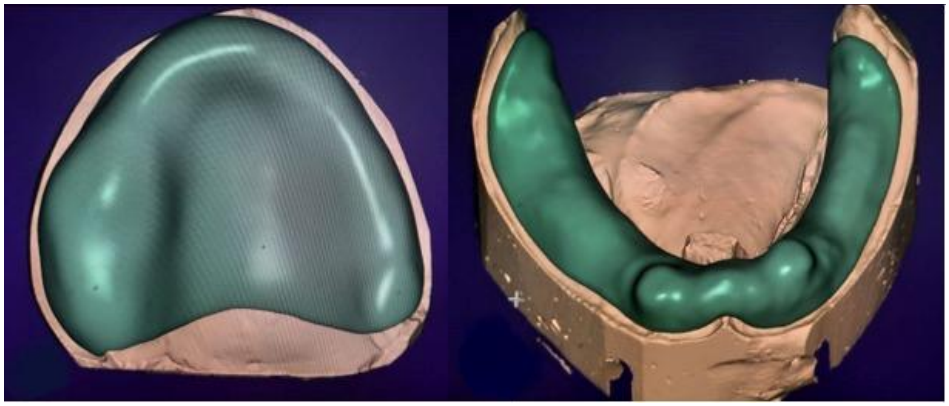

Fig. (8): Planning of record base on designing software

Fig. (9): 3D-printed record bases

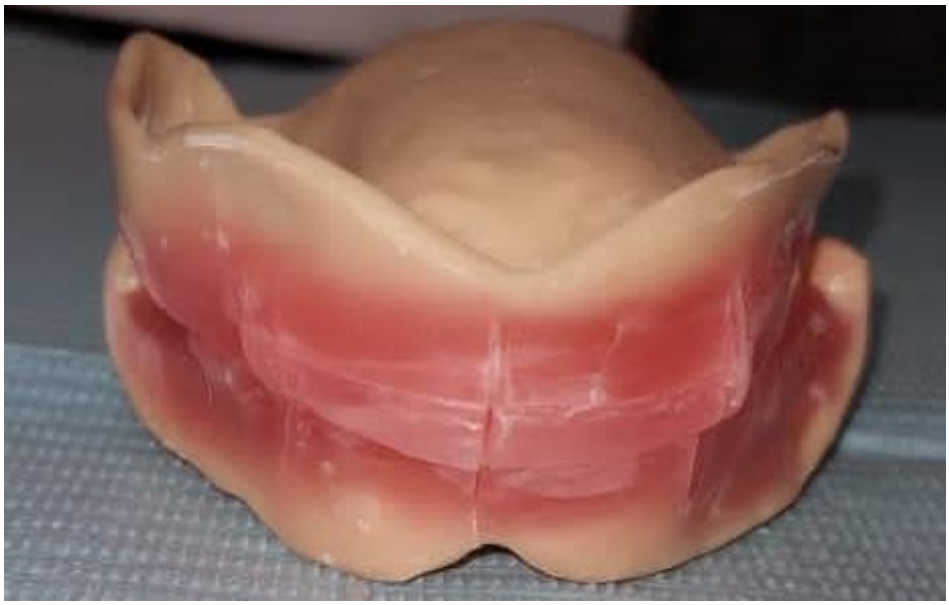

Fig. (10): Jaw relation inter-occlusal record

Scanning and designing of virtual complete overdenture

- The record blocks in the laboratory were scanned digitally in a position close to the clinical situation using the same extra-orally scanner, then the virtual record blocks were saved in (STL) file and imported them into Exocad software that is able to detect point by point matching approach of the anatomical landmarks on the virtual master casts and superimposed with virtual record blocks. **(Fig. 11)**
- The software includes teeth libraries of different brands and shapes. Also possible to customize the set-up by modifying the position or morphology of one or more teeth or even remove them, then teeth set-up as one unit according to jaw relations and the occlusal plane that was defined according to anatomical landmarks and reference lines were determined. To achieve a natural look, the volumes and dimensions of papilla, the marginal curve, the canine eminences and finishing can be adjusted. **(Fig. 12)**

Fabrication of trial complete overdenture

- The virtual complete overdenture (STL) file was used to prepare the trial complete overdenture.
- On software, the virtual final complete overdenture design was split into two printable (STL) files, one of the overdenture base and the second of the teeth.
- Each (STL) file was imported into 3D printing software, and virtual supporting structures were built around the perimeter of the overdenture base file. Also, the arch of the teeth file, the occlusal surface, was oriented toward the build platform with generating supported structures and then uploaded to two separate 3D printers.
- Then, printed with the same steps similar to procedures of record bases by using printing temporary resin material.

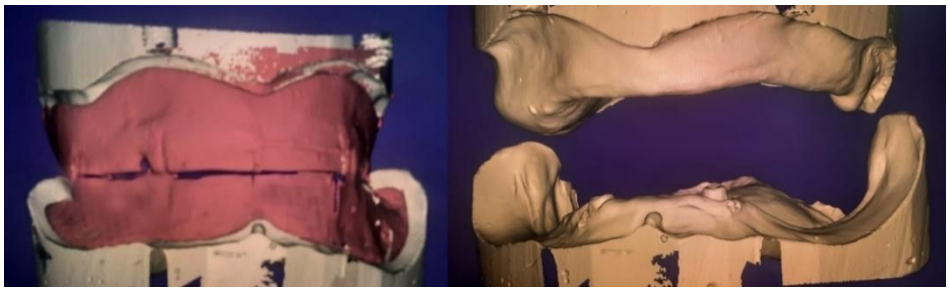

Fig. (11): Jaw relation record was scanned

Fig. (12): Complete overdenture design on Exocad

- After printing was done, rinse, supporting structures were removed, the finished and polished printed overdenture was done with the same conventional method. **(Fig. 13)**
- The trial overdenture is placed intraorally. **(Fig. 14)**
- The maxillomandibular relationship, occlusion, lip support and teeth arrangement were verified.

Fabrication of permanent complete overdenture

- The 3D printer was filled with pink-colored resin material* and overdenture base was printed. Also, dental arch was printed in a tooth-colored resin material** in other 3D printer. **(Fig. 15,16,17)**
- The printed prosthetic parts were removed from platform, and placed in container filled with isopropyl alcohol 99.9% (IPA)*** to rinse off the residual uncured resin, then washing by air dry to remove alcohol from the surfaces.
- After that remaining supporting structures were removed from the printed prosthetic parts and finished by cutting disc and rubber wheel and polished with wet polishing sand using a conventional method. **(Fig. 18)**
- For post-processing polymerization and the printed arch of the teeth was luted to the printed pink base, a small amount of pink denture base resin was applied to the tooth sockets, and the teeth were bonded by placed them in light curing unit**** for 20 minutes until the teeth were set in position and ensure complete polymerization the prosthesis. **(Fig. 19)**
- Finally, the permanent complete overdenture was glazed by using brush with Nano-filled, light cure***** and cured by insert in post curing unit. **(Fig. 20)**

* Denture base resin. ifun. China.
** white dental resin. ifun. China.
*** Isoprppyl alcohol. Petrochem. Dubai.
**** Post curing unit, Mogassam, Egypt.
***** Vita Akzent LC Glaze, USA.

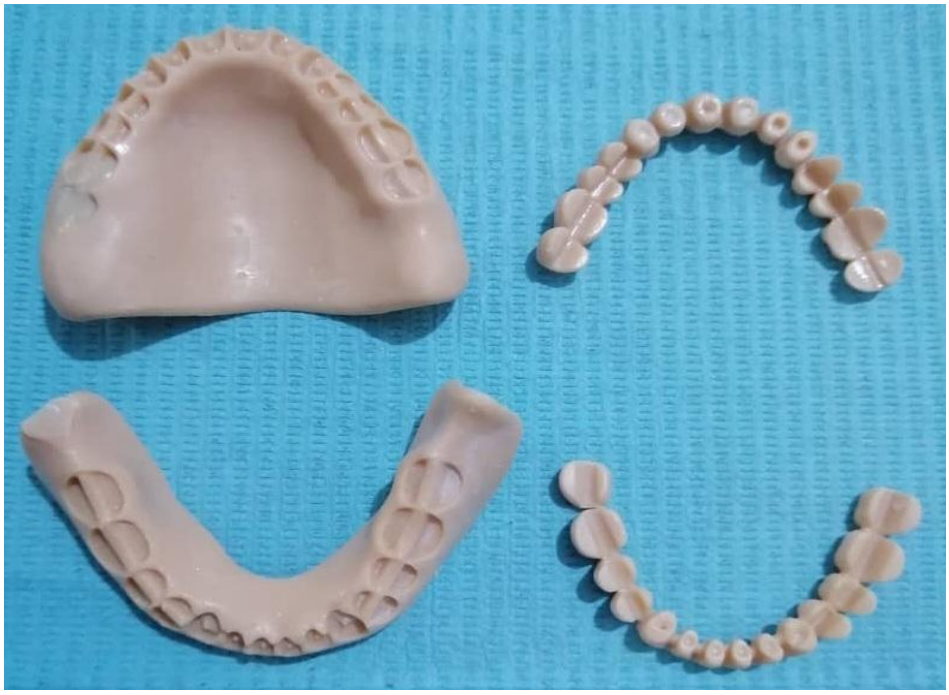

Fig. (13): Trial over-denture was printed in temporary resin material

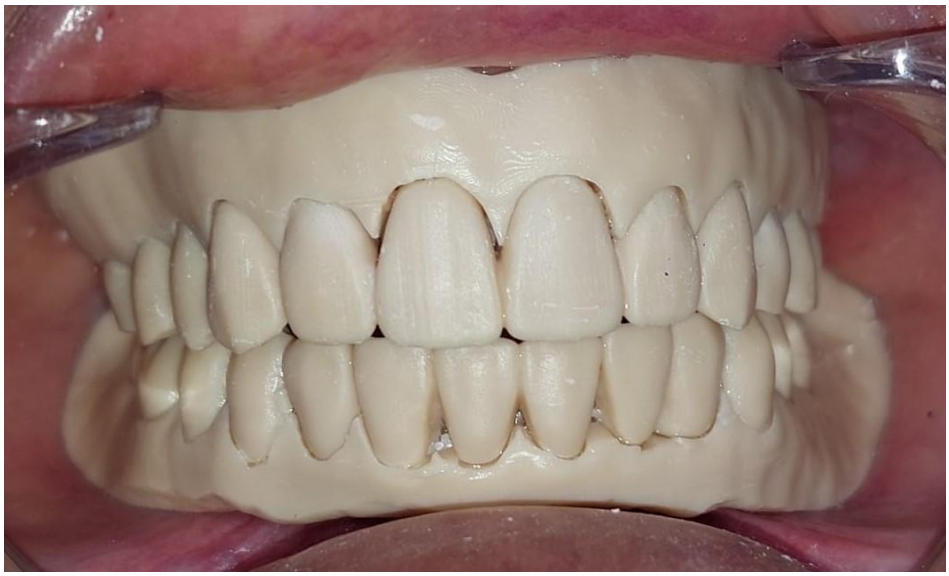

Fig. (14): Try-in of trial complete overdenture

Fig. (15): 3D-printing process of definite complete overdenture in permanent resin material

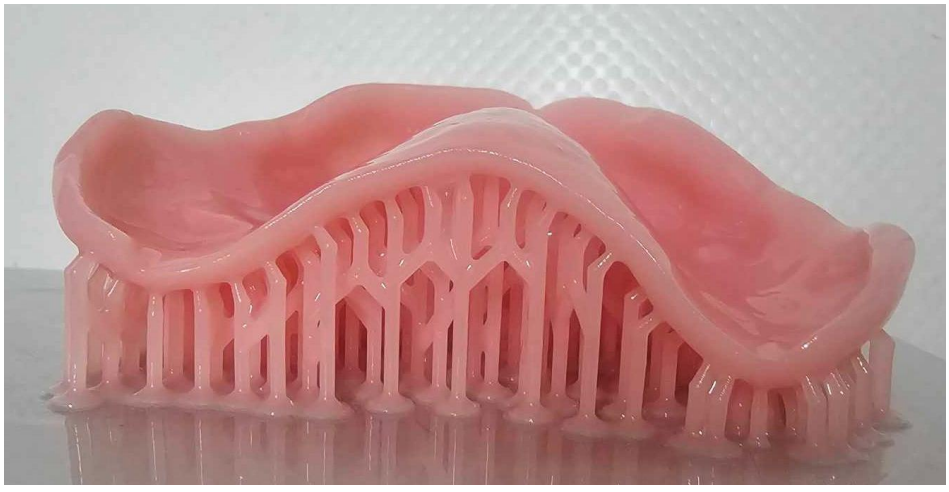

Fig. (16): 3D-printed denture base in pink permanent resin material

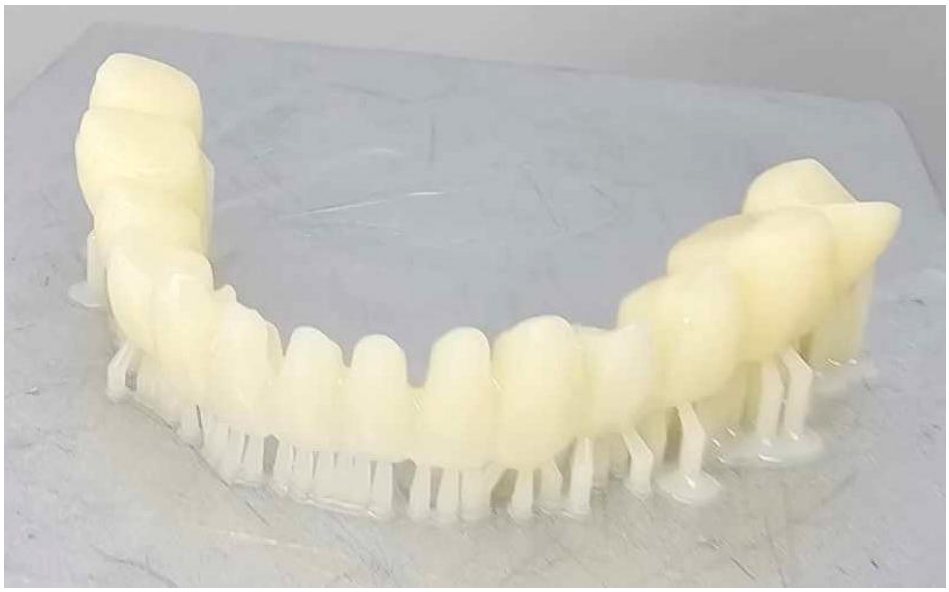

Fig. (17): 3D-printed dental arch in white permanent resin material

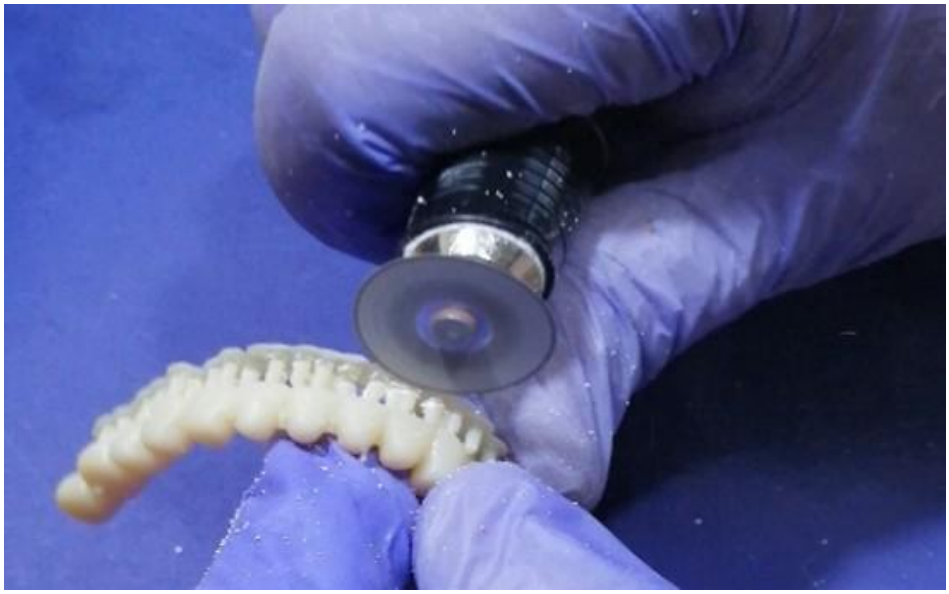

Fig. (18): Removal of supporting structures

Fig. (19): Denture base was bonded to dental arch by the aid of light curing unit

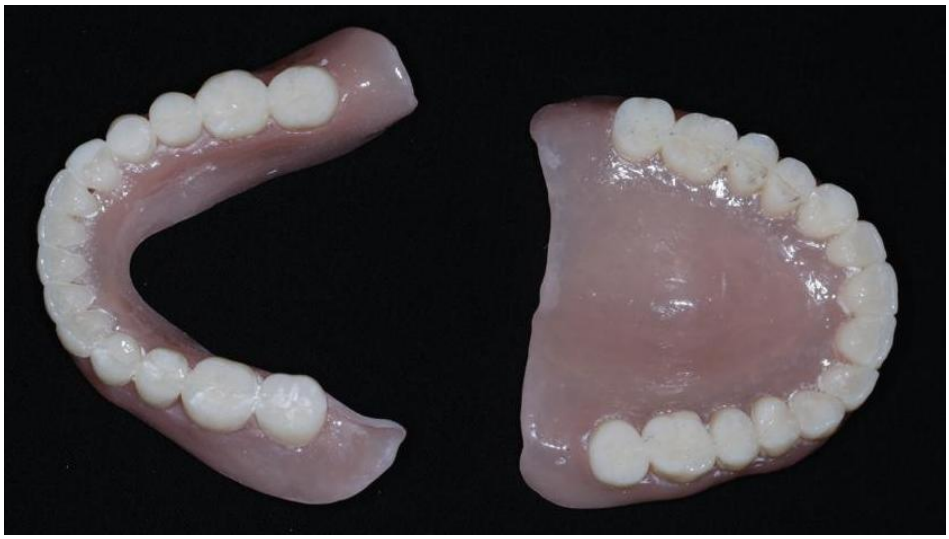

Fig. (20): Definite 3D-printed complete overdenture

Functional pick up of the locator retentive cap

- After complete manufacturing of 3D-printed mandibular denture, the fitting surface opposite to the locator attachments was slightly relieved to allow pick up space for the acrylic resin. Complete freedom of the denture against the attachment assembly was confirmed.
- A small lingual vent holes were prepared opposite to the site of attachment to allow exit for excess of acrylic resin.
- The white locator blocking rings with center hole was fitted around in the gingival region to block the undercut followed by pressing the metal housings with the black lab processing insert directly over locator abutments. **(Fig. 21)**
- The denture was then dried and the relieved areas were slightly coated with acrylic resin monomer.
- Pink auto-polymerized acrylic resin was packed into the attachment houses and the denture was inserted into the mouth against the attachment assembly and the patient was instructed to close in centric occlusion until complete polymerization.

- The denture was removed from the patient's mouth to remove excess resin, finishing and polishing were done and the black processing inserts were replaced by pink nylon inserts of moderate retention values by the aid of the insertion tool. **(Fig. 22)**
- Occlusion was readjusted if necessary to ensure proper occlusal contact to all patients. **(Fig. 23) & (Fig. 24)**

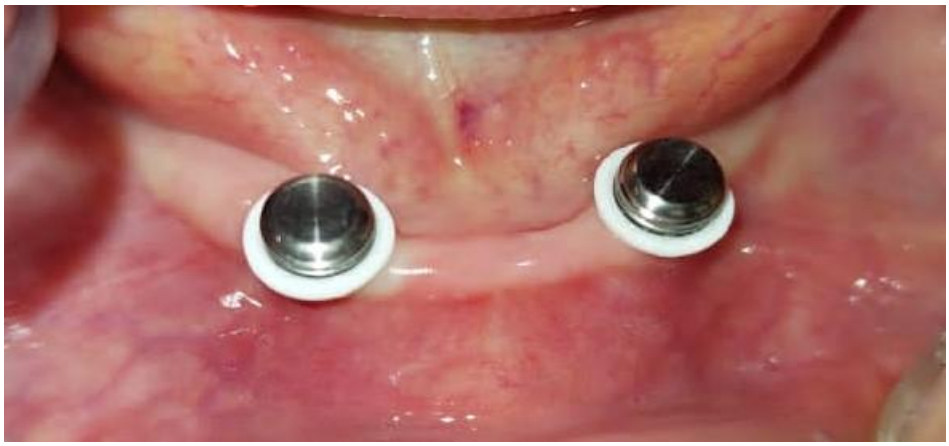

Fig. (21): Metal housing placed over locator attachments with white block-out rings

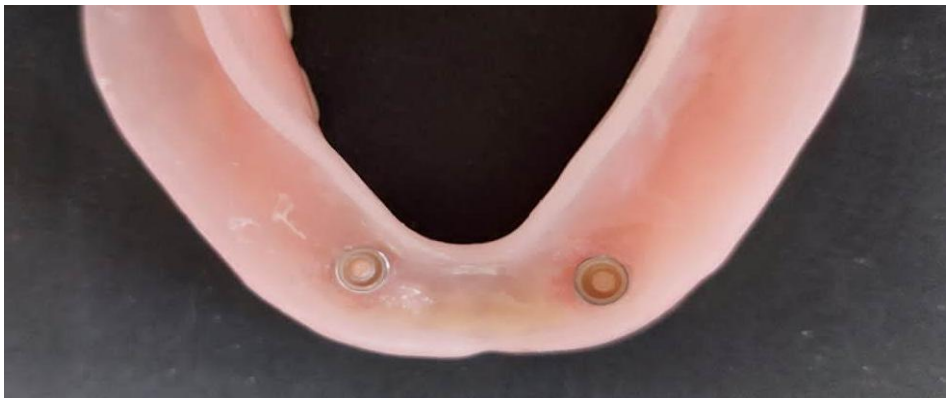

Fig. (22): Mandibular overdenture fitting surface after pick-up procedure

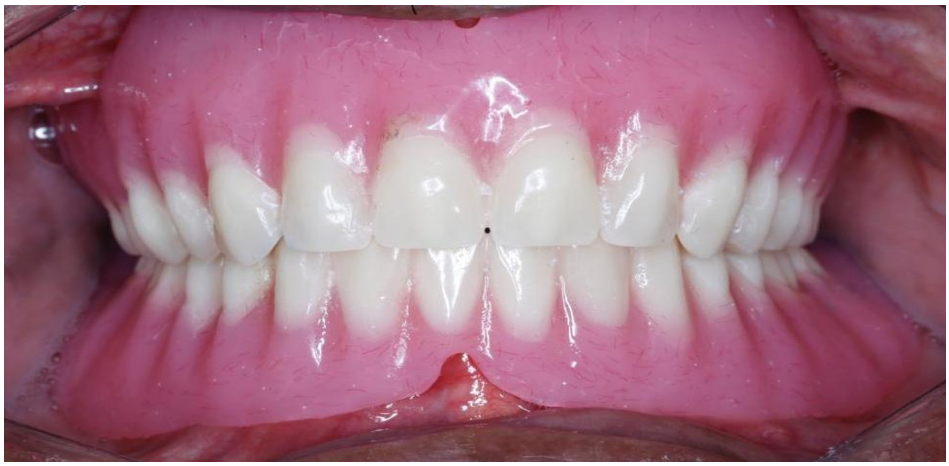

Fig. (23): Conventional complete overdenture inserted intra-orally

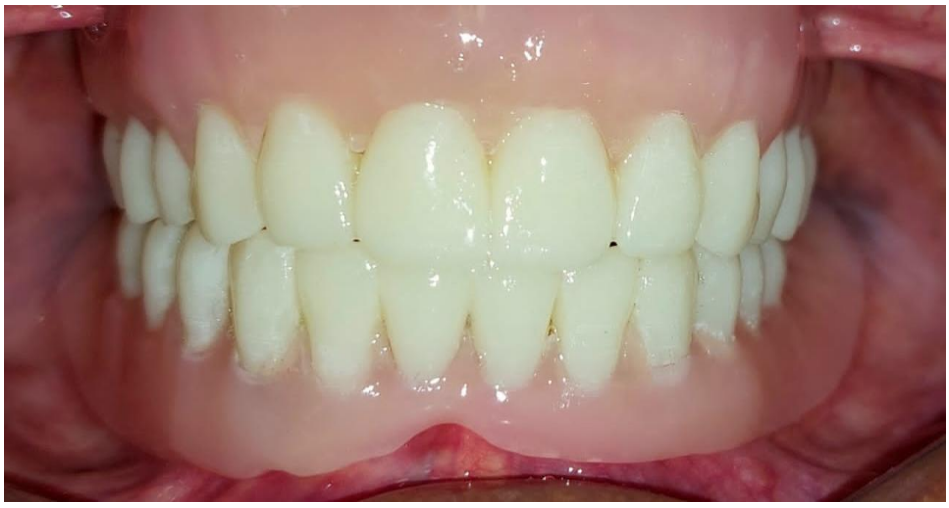

Fig. (24): 3D-printed complete overdenture inserted intra-orally

IV. Evaluation of occlusal force distribution

- The Occlusense system consists from the wireless handheld, sensor, sensor test and iPad-App. **(Fig. 25)**
- The Occlusense was calibrated to ensure the correct recording with was inserted the test sensor inside the handheld after connecting it with the same Wi-Fi connected to the iPad containing Occlusense software. After that, the sensor was removed from its packaging and inserted inside the handheld, the direction and position were determined by the markers on the sensor and by three positioning pins.
- An upright sitting of the patient and sensor was inserted into his mouth and started to bite on the sensor according to the instructions of the operator and the pink button was pressed and the occlusal state was recorded. **(Fig. 26)**
- The recording ended automatically and the data was saved locally on the handheld, then transmits to the iPad-App through a wireless connection.
- The sensor was removed from the patient's mouth. After that, the data was stored in the patient file in iPad-App.
- A graphic of data was then viewed in 2D or 3D or in a combined view. **(Fig. 27)**
- The sensor was removed from the handheld and disposed properly after the desired recordings have been made.
- Cleaning and disinfection procedures were performed.
- These recordings were evaluated at three different times. (T0) at the time of overdentures being inserted, (T6) after 6 months, and (T12) after 12 months from overdenture delivery.

Fig. (25): Components of Occlusense device

Fig. (26): Measurement of occlusal force distribution using Occlusense

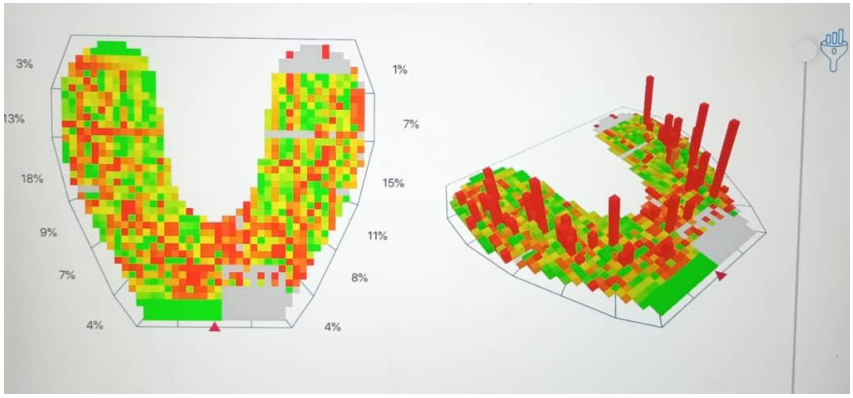

Fig. (27): Graphic 2D and 3D views of occlusal force distribution

V. Evaluation of occlusal wear

- Each patient's occlusal surface wear was evaluated using 3D digital analysis, which involved scanning the mandibular and maxillary overdentures with an intraoral scanner* to create 3D virtual overdentures. **(Fig. 28)** Once the scan was complete and all teeth surfaces had been recorded, the scans were exported and saved to (STL) files.
- These scans were saved at three different times. (T0) at time of overdentures inserted, (T6) after 6 months and (T12) after 12 months from overdentures delivery.
- Each pair of (STL) files were superimposed by using (Medit link software)** the software automatically best-fit alignment technique was used to superimposition of the pair scans. Then was selected different points on occlusal surfaces of all teeth (incisal edge, cusp tips, slopes and marginal ridges). The differences between the points were examined. **(Fig. 29)**
- The (STL) file of the overdenture after 6 months of insertion (T6) was compared to the baseline (T0) to determine amount of wear encountered after 6 months of use, then (STL) file of the denture after 12 months of insertion (T12) again was superimposed to baseline to determine amount of wear encountered after 12 months of use.

* Medit i700. Korea.
** Medit, korea.

Fig. (28): Medit I700 intra-oral scanner

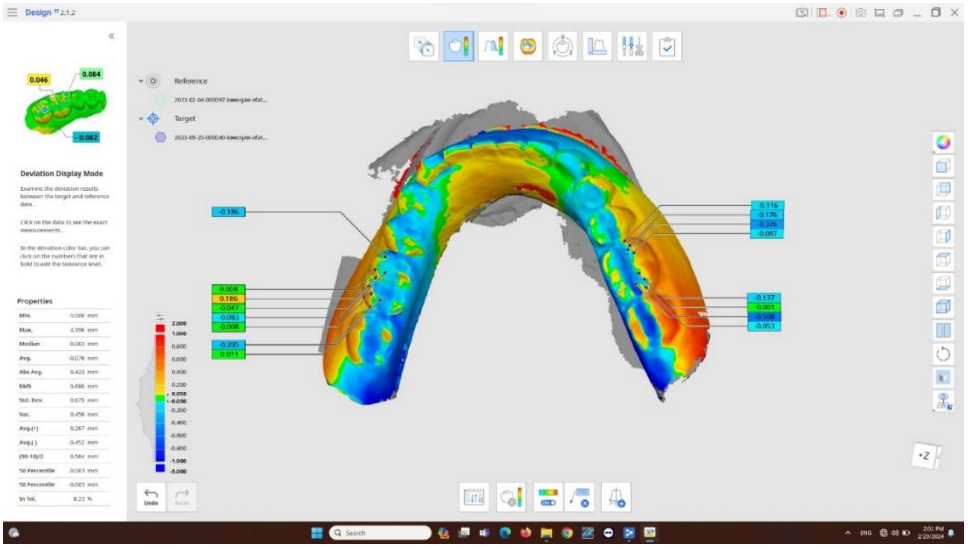

Fig. (29): Evaluation of occlusal wear using 3D digital analysis

VI. Evaluation ofpatient satisfaction

Thirteen questions on a questionnaire were used to gather data on patient satisfaction. The questionnaire was created by ten specialists (periodontists, general dentists, radiologists, and maxillofacial surgeons) in Arabic language and used after the validation of its content validity ratio (CVR) and content validity index (CVI). The patients answered the questionnaire's questions 3 months post-prosthetic delivery during an interview. Each question had multiple answer choices and was scored as follows: never (4), sometimes (3), often (2) and always (1). Therefore, the total satisfaction score ranged from 0 to 52. A higher score indicated lower level of problems. The percentage of satisfaction was determined using the equation below:

$$\text{Satisfaction rate} = \frac{\text{Obtained score x 100}}{52}$$

Statistical analysis

Data were analyzed using the Statistical Package of Social Science (SPSS) program for Windows (Standard version 26). The normality of the data was first tested with the Shapiro test.

Continuous variables were presented as mean ± SD (standard deviation) for normally distributed data. The two groups were compared with an independent t test, while paired groups were compared with a paired t-test. The threshold of significance is fixed at the 5% level (P-value). The results were considered significant when the $P \leq 0.05$. The smaller P-value obtained, the more significant the results.

Results

Table (1): Comparison of occlusal wear between Conventional and Digital constructed overdentures after 6 months (T6) and 12 months (T12).

Occlusal wear		Conventional group (n=3)	Digital group (n=3)	Independent t- test	P-value
T6	Incisors	0.029±0.01	0.086±0.01	t=10.228	**≤0.001***
	Premolars	0.048±0.02	0.106±0.02	t=-4.890	0.001
	Molars	0.026±0.01	0.097±0.02	t=8.293	**≤0.001***
T12	Incisors	0.043±0.02	0.145±0.01	t=10.612	**≤0.001***
	Premolars	0.076±0.02	0.169±0.01	t=8.979	**≤0.001***
	Molars	0.065±0.02	0.157±0.01	t=8.713	**≤0.001***
Paired t-test	Incisors	**P=0.018***	**P≤0.001***	-	-
	Premolars	**P≤0.001***	**P≤0.001***	-	-
	Molars	**P=0.026***	**P≤0.001***	-	-

Digitally constructed overdentures showed statistically significant occlusal wear than Conventional overdentures group at T6: incisors (P≤0.001), molars (P≤0.001), and at T12: incisors (P≤0.001), premolars (P≤0.001), molars (P≤0.001).

Both groups showed significant occlusal wear with advance of time for incisors (Conventional P=0.018, Digital P≤0.001), premolars (Conventional P≤0.001, Digital P≤0.001), and molars (Conventional P=0.026, Digital P≤0.001).

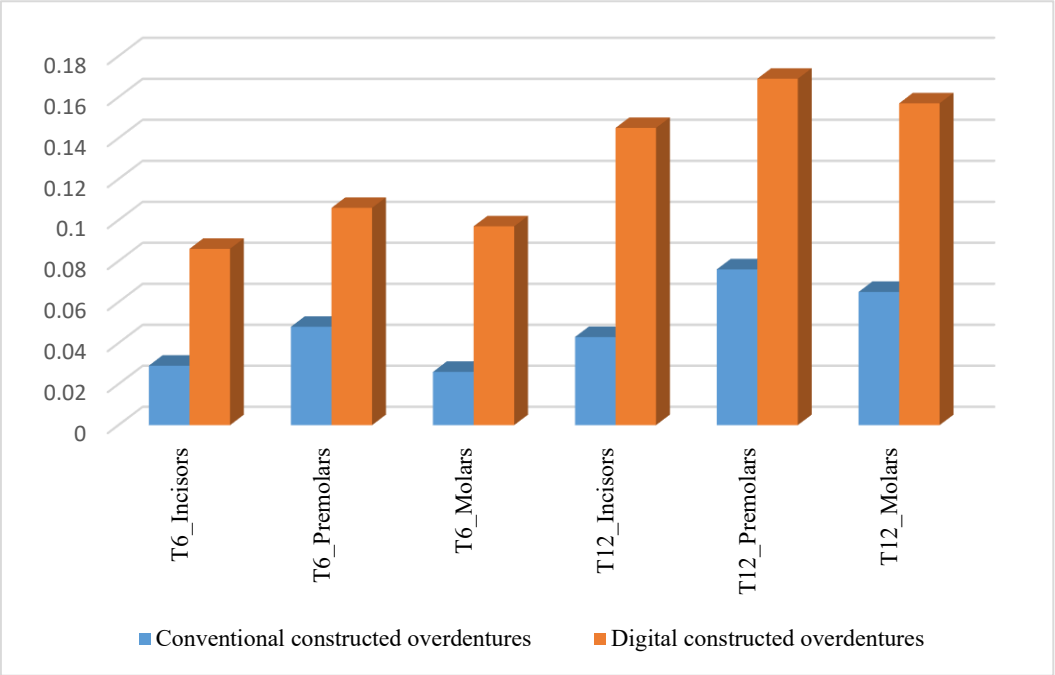

Figure (30): Occlusal wear values for Conventional constructed overdentures and Digital constructed overdentures

Table (2): Comparison of occlusal force distribution between Conventional and Digital constructed overdentures after 6 months (T6) and 12 months (T12).

Occlusal force distribution		Conventional group (n=3)	Digital group (n=3)	Independent t- test	P-value
T0	Incisors	15.83±2.31	15.16±3.65	t=0.377	0.714
	Premolars	51.16±3.12	54.00±5.17	t=1.148	0.278
	Molars	33.00±4.33	30.83±7.02	t=0.643	0.535
T6	Incisors	20.83±2.78	17.50±1.87	t=2.433	**0.035***
	Premolars	48.33±2.87	46.83±2.92	t=0.896	0.392
	Molars	30.83±2.85	35.66±4.32	t=2.286	**0.045***
T12	Incisors	25.50±3.78	20.83±2.85	t=2.412	**0.037***
	Premolars	47.17±3.18	40.33±3.07	t=3.778	**≤0.004***
	Molars	27.33±4.63	39.33±3.20	t=5.218	**≤0.001***
Paired t-test	Incisors	**P1=0.005*** **P2=0.002*** **P3=0.002***	P1=0.152 **P2=0.025*** P3=0.059	-	-
	Premolars	**P1=0.013*** P2=0.402 P3=0.073	**P1=0.001*** **P2=0.003*** **P3=0.002***	-	-
	Molars	P1=0.163 P2=0.055 P3=0.084	**P1=0.036*** P2=0.079 **P3=0.048***	-	-

*significant P≤0.05 (P1: T0 vs. T6 - P2: T6 vs. T12 - P3: T0 vs. T12)

Both groups showed statistically insignificant difference of mean occlusal forces at T0 for incisors, premolars, molars (P≥0.05). At T6 there was statistically significant difference between groups in incisors (P=0.035), molars (P=0.045). Also, at T12 there was significant difference between both groups in incisors (P=0.037), Premolars (P≤0.004), molars (P≤0.001).

Conventional overdentures group showed significant occlusal force distribution with advance of time for incisors (P1=0.005) from T0-T6, (P2=0.002) from T6-T12, (P3=0.002) from T0-T12, in premolars there was significant difference (P1=0.013) from T0-T6, in molars there was no significant difference with advance of time T0-T6 (P1=0.163), T6-T12 (P2=0.055) and T0-T12 (P3=0.084).

Digital overdentures group showed significant occlusal force distribution with advance of time for incisors (P2=0.002) from T6-T12, in premolars there was significant difference from T0-T6 (P1=0.001), T6-T12 (P2=0.003), T0-T12 (P3=0.002), in molars T0-T6 (P1=0.036), T0-T12 (P3=0.048).

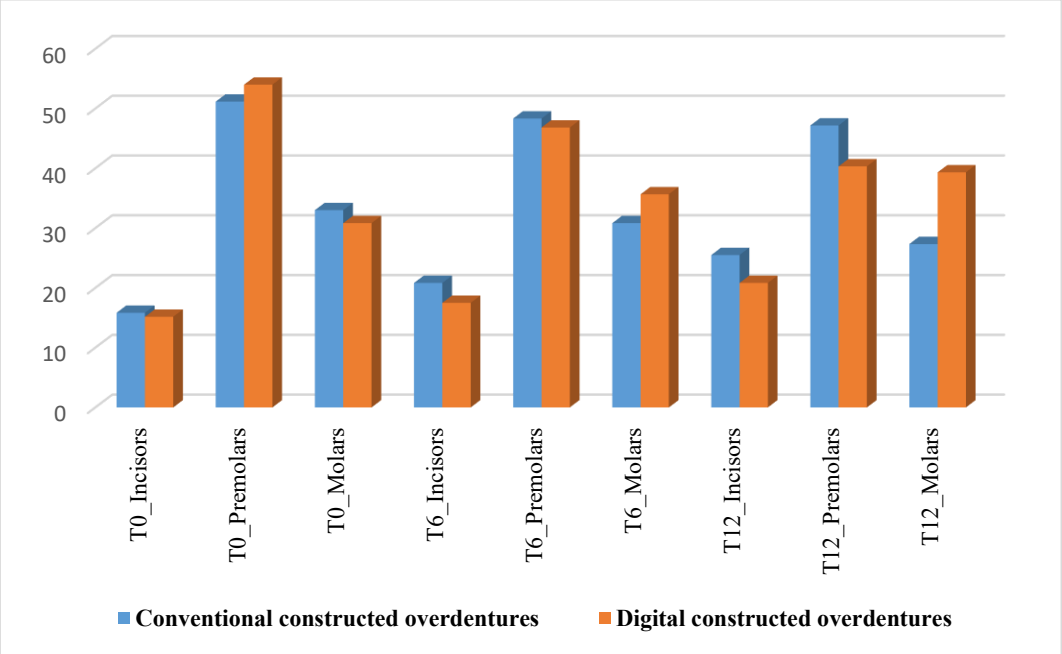

Figure (31): Occlusal equilibration for Conventional and Digital constructed overdentures

Table (3): Comparison of patient satisfaction between Conventional and Digital constructed overdentures after 3 months.

Patient satisfaction	Conventional group (n=3)	Digital group (n=3)	Independent t- test	P value
Problems with pronunciation of some words	3.30±0.82	1.70±0.82	t=4.34	**≤0.001***
Instability during speaking	1.80±0.78	2.20±0.79	t=3.96	**≤0.001***
Difficulty during opening	3.30±0.82	3.30±0.78	t=4.16	>0.05
Interference during eating or speaking	3.30±0.78	3.30±0.82	t=4.16	>0.05
Change in sense of taste	3.30±0.82	3.20±0.78	t=4.16	>0.05
Pain or discomfort when using denture	1.80±0.78	3.30±0.82	t=4.16	**0.001***
Pain or discomfort when eating by using denture	1.70±0.82	3.30±0.82	t= 4.34	**≤0.001***
Food impaction under denture	3.20±0.82	3.20±0.92	t=3.84	**0.001***
Sense of mouth fullness	3.30±0.82	1.72±0.82	t=4.34	**0.001***
Instability during eating	1.80±0.78	3.10±0.88	t=3.48	0.003
Difficulty in swallowing liquids	3.20±0.82	3.20±0.78	t=4.16	>0.05
Change in appearance with denture	3.20±0.82	1.70±0.78	t=4.16	**0.001***
Denture is not as expected	3.20±0.74	3.30±0.82	t=4.01	**0.001***
TOTAL	36.60±2.16	38.52±2.99	t=16.59	≤0.074
Patient satisfaction %	70.38±4.16	74.07±5.78	t=16.54	≤0.074

Regarding patient satisfaction, there was a common statistically insignificant difference between groups (P≤0.074) in general patient's satisfaction parameters. However, conventional overdentures group the patients were significantly satisfied in terms of esthetics (P=0.001) and phonetics (P<0.001) than digital constructed overdentures group. On the other hand, digitally constructed overdentures group showed superior

patient satisfaction regarding retention and stability during function (P≤0.001).

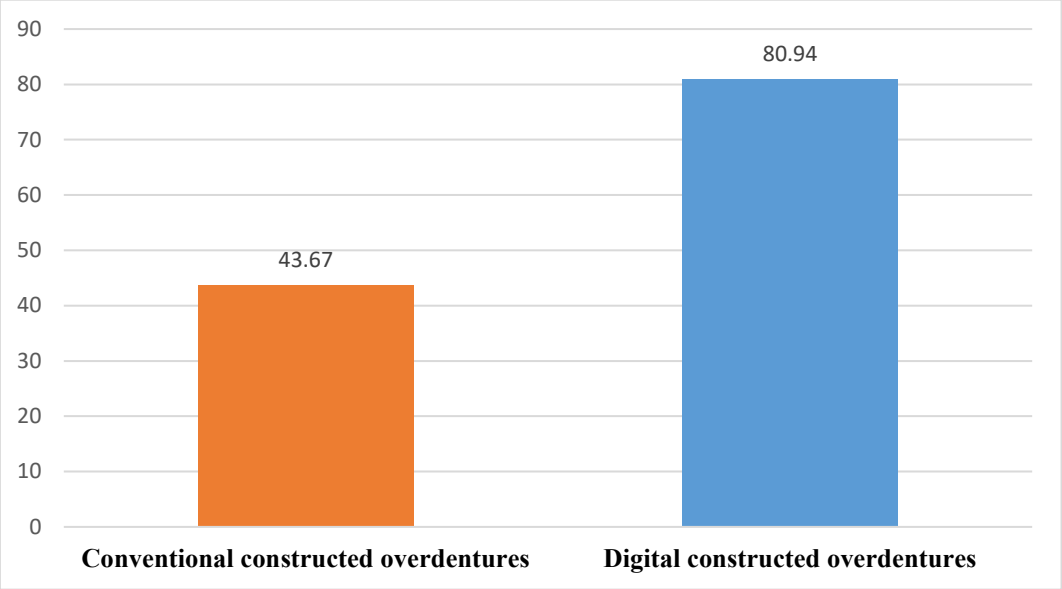

Figure (32): Patient satisfaction for conventional and Digital constructed overdentures after 3 months.

Discussion

This study was done to evaluate two different overdenture construction techniques, conventional versus complete digital workflow for two implant-retained complete mandibular overdentures regarding occlusal wear, occlusion force distribution and patient satisfaction after different observation periods within one year of study.

Poor mechanical properties of the conventional denture bases and artificial teeth materials are the most common cause of clinical failure. The hardness of the resin denture base material is an important factor determining the resistance to abrasion and hence surface roughness and microbial adhesion. Moreover, the flexural modulus reflects the material's stiffness and rigidity as well as the ability of the material to equally distribute the forces to the underlying structures.[150]

Although conventional construction of heat cured resin denture bases and artificial teeth has been used for up to one century, complete digital workflow technique for denture bases and artificial teeth were recently introduced and result in reduced laboratory and clinical costs, less frequent appointments of the patient to the clinician, reduced clinical chair time, expedited treatment, creating a virtual digital database of prosthetics for future treatment needs, and a lower overall burden on edentulous patients.[151, 152] However, it is a pressing issue to follow the progress and improvements in the prosthodontic rehabilitation field which always undergoes rapid alterations in the expense of patients satisfaction and high rate of accurate successful treatment approaches. This study was aimed to monitor the benefits of digital workflow from three important aspects. One aspect concerned the patient satisfaction and two aspects concerned the serviceability of the digitally used material for the artificial teeth regarding the mechanical wear and the occlusal force as major biomechanical factors.

Discussion of materials and methods:

Healthy Patients free from systemic diseases were selected for this study, because presence of systemic diseases decreases the patient's tolerance to dental treatment.[153] Patients with cardiovascular diseases may experience increased bleeding, high blood pressure or even ischaemic attacks during implant surgery.[155 ,154] The hypothesis of a higher risk of failures in patients with cardiovascular diseases is related to the possibility that the impaired blood supply and the consequent hypoxia may negatively affect the healing process of bone around implants.[156]

Patients under radiotherapy were excluded because it reduces cellular and vascular growth and therefore may significantly impair osseointegration of dental implants and increase the risk of complications (for example, osteoradionecrosis).[157] it was reported that the late radiotherapy effects involve bone changes and may lead to demineralization, fibrosis, increased susceptibility to infection and a vascular necrosis.[158]

Immuno-compromised patients are excluded from study as a good immune response is important for wound healing, therefore it is reasonable to speculate that immuno-compromised patients may be at higher risk of implant failure.[159, 160]

Osteoporotic patients were not included in this study as they are characterized by a reduction in bone density and alterations in the microstructure of bone that lead to an increased risk of fractures.[161] Impaired bone metabolism in osteoporotic patients can impair bone healing patients under chemotherapy were not included in study as it may interfere with bone turnover at the dental implant interface, reducing implant success and increasing the risk of developing osteonecrosis of the jaws (ONJ).[162]

Smokers were not included in study as smoking in general is associated with healing complications in oral surgery and periodontology, such as dry socket, slow epithelialization in free gingival graft donor sites, and a poor prognosis for periodontal treatment. Implant loss, infection, and inflammation of the peri-implant mucosa, with or without bone loss, are among the most common complications of implant treatment when associated with smoking.(163) As a general rule, surgeons ask their patients to stop smoking before any surgical procedure. Nevertheless, short-term smoking cessation does not seem to decrease the rate of complications in colorectal surgery, because it seems to reduce the altered chemotaxis of macrophages and neutrophils only marginally.(164) However, a recent systematic review of randomized controlled trials on smoking cessation showed that intensive programs performed at least 4 weeks before surgery seemed to improve the results and increase the cessation rates.(165)

Diabetic patients were not selected in this study as diabetes has adverse effect on osseointegration, it has been associated to reduced bone mineral density, increased risk of fractures, reduced bone mechanical properties, impaired endochondral and intramembranous bone formation and impaired micro architectural quality of bone, also hyperglycemia may lead to severe complications like macro/micro angiopathy, neuropathy and increased risk of infections.(155, 166, 167)

All patients included in this study were completely edentulous maxilla and mandible for at least six months before implant placement. It was recognized that waiting for complete healing of the site may still be the treatment of choice. As a healing period of four to twelve months prior to implant placement was considered the standard of care because a fully healed ridge ensures implant insertion in a stable ridge dimension. In cases where pathology has completely affected the socket integrity, primary

stability of an implant cannot be attained, or limiting anatomical structures are difficult to avoid, However, in many of these cases the bone availability for an implant to be placed an optimal 3D implant position may not always be ideal due to the resorptive changes after tooth extraction; therefore, regenerative procedures may be required.[168]

Healthy firm mucosa was required for this study to aid in stability of overdentures prosthesis during function.[169] As De Boer 1993 concluded that overdentures restorations require a non-mobile bearing tissues to avoid dislodging forces.

Angle's class I maxillomandibular relationship was chosen in this study to minimize unnecessary occlusal stresses that are induced by class II and class III maxillomandibular relationship.[170] Sufficient inter-arch space was selected because implant-retained restorations require a minimum amount of interarch space to provide an esthetically acceptable result and long-term function with reduced incidence of complications. However, a minimum 9 mm iter-arch space is recommended for low profile locator attachments.

Good oral hygiene was necessary in this study because oral hygiene is an important factor in implant success, as the oral flora associated with healthy gingiva has been found to be the same as that found around healthy implant sites. Conversely, there are similarities between the microbial composition associated with gingivitis and peri-mucositis and that associated with periodontitis and peri-implantitis. Patients with poor oral hygiene have an increased risk for peri-implantitis and implant failure.[171]

Patients with history of para-functional habits like bruxism and clenching were excluded as these habits were found to be one of the most common causes of implant bone loss or lack of rigid fixation during the first year after implant treatment.[172] Bruxism in this study is considered a

very strong variable that has a high impact on the occlusal wear and occlusal force. Also, patients with disorders of the Temporomandibular joint (TMJ) have been excluded as they cause an adverse effect on jaw function so that patients may present with limited mouth opening or pain and locking in the Temporomandibular joint (TMJ).[173] However, it was agreed that TMJ disorders are major contributing factor that accelerate the occlusal wear and affect the occlusal forces.

Balanced lingualized occlusion was followed in this study since it preserves the edentulous ridge and influences the stability of overdentures.[174] Bilaterally lingualized balanced occlusion is indicated in cases of mandibular overdentures supported by few implants occluding with complete maxillary dentures. This type of balanced occlusion provides for the primary stability of the dentures during functional loading. Also, it allows even distribution of load between implants and denture bearing tissues.[175]

Extraoral scanning for 3D-printed group was employed for digitizing the master cast obtained by the conventional impression technique. The use of extraoral 3D scanners offers several advantages in capturing highly detailed and precise digital representations of the master cast. Additionally, the extraoral scanning method in this study played a crucial role in generating accurate digital models. The generated (STL) file format provides an accurate virtual replica of the master cast, enabling precise fabrication of prosthetic components through CAD/CAM technologies.[176, 177]

After printing, the printed overdentures base and teeth were washed with isopropyl alcohol in water path vibrator to remove any access monomer as prescribed by manufacture instructions. The teeth are bonded to the base with denture base resin. For completing the curing cycle the

dentures were placed in light curing unit for 20 minutes. Patient was instructed for denture cleansing and proper oral hygiene and to review any denture complain. The microporous surfaces of an acrylic denture provide a wide range of environments to support microorganisms that can threaten the life.[178]

Functional pick- up technique of the retentive caps of locator attachment was used as this technique is simple, economic, and quick, require less prosthetic elements and the patient occlusion aided to obtain the proper position and seating of the prosthesis.[179] Also it has the advantage is that the attachment can be made in a passive, loaded (bite force) environment to ensure complete seating of denture on the underlying tissues and to overcome the dimensional changes associated with transfer impression and laboratory processing technique causing errors preventing the housing from seating properly on the abutment resulting in an overdentures requiring less maintenance, less replacement of worn attachments parts and aftercare.[180]

Digital occlusion analysis using Occlusense is an attempt to bring better care to patients by being able to see and analyze data that analogue methods and non-digital techniques cannot provide. The goals are to help dentists make sense of Occlusion. The data can be displayed graphically 2D and 3D, including the distribution of the masticatory forces recorded digitally.[139] The bilateral balanced occlusion criteria are normally the recommended occlusal scheme for overdentures. (Occlusense) divides the arch into anterior, premolar, and molar parts to display the average occlusal forces in percentages (%) for each segment of the dentition. (Occlusense) data analysis relies on achieving a uniform distribution of occlusal force bilaterally and anteroposteriorly.[181]

Digital matching software in mechanical wear was done in this study as the result can be visualized in all dimensions of space and quantified according to the clinician's needs, as a linear or volumetric quantity. Apart from tooth wear, the present technique is expected to be suitable for dental material wear assessment, especially on the occlusal/incisal tooth surfaces, but this remains to be tested. Numerous surface matching software applications have also become widely available, though their performance for such outcomes has to be individually tested.[127]

Discussion of results:

In the present study, digital constructed overdentures group showed statistically significant occlusal wear than conventional constructed overdentures group at T6: incisors ($P \leq 0.001$), molars ($P \leq 0.001$), and at T12: incisors ($P \leq 0.001$), premolars ($P \leq 0.001$), molars ($P \leq 0.001$). This may be due to the relatively minimal hardness of 3D-printed resin material compared with heat polymerized material, which leads to more wear of 3D-printed teeth over time.

This finding is in agreement with Gad et al., who compared 3D-printed denture base resin with heat polymerized acrylic resin before and after thermal cycling and showed that the 3D-printed resin had the lowest hardness. This result may be due to the material composition, where 3D-printing involves the use of monomers based on acrylic esters and has relatively low double-bond conversion compared with conventional acrylic resins.[182]

Also, Abdelrahim et al., reported a higher hardness value of CAD/CAM denture base material, followed by the conventional heat polymerized material, the lower hardness value with the 3D-printed material.[150]

It was agreed that one of the key factors influencing resistance to abrasion and wear, as well as surface roughness and microbial adherence, is the hardness of the resin denture base material.[70]

After six and twelve months (T6 &T12) this study showed that there was a statistically significant difference between both groups over time, comparing between groups regarding occlusal force distribution. At T6 there was statistically significant higher occlusal force distribution in digital constructed overdentures group compared with conventional constructed overdentures group in incisors (P=0.035), molars (P=0.045). Also, at T12 there was significant difference between both groups at incisors (P=0.037), Premolars (P=0.004), molars (P≤0.001). This may be due to the lower modulus of elasticity (rigidity and stiffness) of 3D-printed material than in conventionally material. Although denture bases made with 3D-printing represent a novel approach to denture manufacturing, their flexural strength values are currently lower than those of the majority of denture base materials.[183] which explains the difference between groups over time, with more occlusal force distribution in the digital constructed overdentures group than the conventional one.

Resulting from better denture material adaptation to the underlying structures of digital constructed overdentures over time, while the conventional constructed overdentures material has a high modulus of elasticity providing less force distribution to the underlying structures over time.

Gad et al., compared 3D-printed denture base resin with heat polymerized acrylic resin before and after thermal cycling and showed that the 3D-printed resin had the lowest flexural strength and impact strength. This result may be due to the material composition, where 3D-printing involves the use of monomers based on acrylic esters and has relatively

low double-bond conversion compared with conventional acrylic resins.[182]

This finding is also agreed with a study by Abdelrahim et al.[150] comparing the CAD/CAM-milled material. They reported a higher flexural modulus, followed by the conventional heat polymerized material, while and a lower flexural modulus with the 3D-printed material.

The stiffness and rigidity of the material are reflected in its modulus of elasticity. A higher flexural modulus is often advantageous in clinical settings because denture base materials with high elastic moduli are more resistant to elastic deformation. Although the flexibility of the denture base is helpful in increasing the absorbed energy before fracture, the rigidity of the denture framework is a prerequisite for the ability of a denture base to equally distribute forces to the underlying structures.[184]

Prpi´c et al.[70] added that the CAD/CAM materials exhibited higher flexural strength than heat polymerized and 3D-printed acrylics, and 3D-printed acrylics have lower mechanical properties than most other denture base materials.

Regarding patient satisfaction there was insignificant difference between groups ($P \leq 0.074$). Nonetheless, our findings indicated that conventional constructed overdentures group were significantly higher than digital constructed overdentures group in terms of several assessment items related to patient satisfaction as esthetics and phonetics.

Also, digital constructed overdentures group showed superior results in other patient satisfaction items like retention and stability during function. The primary reason for this outcome may be attributed to the disparity in manufacturing techniques between the digital constructed overdentures group, which are constructed with a palatal thickness of 2.5

mm for enhanced strength, and the conventional constructed overdentures group, which are fabricated with a thickness comparable to that of a paraffin wax sheet (approximately 1.4 mm).

This is evidenced by the markedly greater satisfaction levels in the phonetics of the conventional constructed overdentures group compared to the digital constructed overdentures group. The markedly greater satisfaction with ease of cleaning and color stability in conventional constructed overdentures group compared to digital constructed overdentures group may be ascribed to the variation in the type of artificial teeth employed. While 3D-printed artificial teeth possess physical characteristics akin to those of resin teeth.[185]

Digital constructed overdentures group may exhibit discoloration more rapidly than conventional constructed overdentures group. This may possibly be a primary element influencing our outcomes.

The greater satisfaction among the digital constructed overdentures group in terms of stability and comfort may be ascribed to the enhanced fit and adaption of the digital constructed overdentures bases. Numerous articles assert that 3D-printed overdentures bases exhibit enhanced retention relative to conventionally produced bases.[185]

In contrast, multiple studies have demonstrated that entire dentures manufactured using 3D-printing are comparable to those made by traditional methods regarding retention.[186] Conversely, a study reported that 3D-printed denture bases exhibit lowest adaptability relative to milled and conventionally pressed denture bases.

Numerous investigations have verified that dentures produced by conventional methods experience significant dimensional changes. This primarily arises from the dissipation of internal stress and polymerization

contraction. This dimensional alteration will negatively impact the retention, stability, and support of the prosthesis, hence reducing patient satisfaction. This significant constraint has become the enhancement of entire denture manufacturing procedures an essential requirement.[187]

Conclusion

Within the limitations of this study, including the patient number and time interval, it could be concluded that:

1. Implant overdentures constructed by conventional techniques maintain the occlusal table after one year of overdenture insertion compared to digitally constructed overdentures.
2. Digitally constructed implant retained overdenture favorably distribute the occlusal force than conventionally constructed overdentures.
3. Implant retained overdenture construction techniques has no impact on patient satisfaction.

Recommendations

1. Further studies on a large number of patients are needed for further investigations and increased evaluation time.
2. Other types of manufacturing techniques are needed to be studied and compared.

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الملخص العربي

الهدف من الرسالة:

أجريت هذه الدراسة السريرية لتقييم تقنيتين لصناعة أطقم الأسنان الكاملة المستبقاة على غرسات للفك السفلي: التقنيات التقليدية مقابل تقنيات الرقمية الكاملة من حيث تأكل سطح الأسنان، وتوزيع قوة العض الإطباق ورضا المريض.

الإجراءات العلمية:

اختير ستة مرضى لهذه الدراسة من قسم الأستعاضة الصناعية بكلية طب الأسنان بجامعة المنصورة. تلقى كل مريض غرستين في منطقه الاماميه للفك السفلي مع تحميل الأطقم على الغرسات عن طريق الوصلات المكانيه لكل مريض وفقًا لتقنية صناعة أطقم الأسنان ، تم تقسيم جميع المرضى عشوائيًا إلى مجموعتين متساويتين. المجموعة الاولى: أطقم الأسنان تقليدية الصنع، والمجموعةالثانية: أطقم الأسنان رقمية الصنع بالكامل. تم تقييم جميع أطقم الأسنان من حيث التآكل لسطح الأسنان باستخدام التحليل الرقمي ثلاثي الأبعاد، وكذلك توزيع قوة الإطباق باستخدام نظام تحليل الإطباق الرقمي فورًا، وبعد ستة أشهر، وبعد اثنى عشر شهرًا من التركيب، وكذلك رضا المريض بعد ثلاثة أشهر من تركيب طقم الأسنان باستخدام استبيانات المرضى.

النتائج :

أظهرت أطقم الأسنان المصممة رقميًا تآكلًا ذا دلالة إحصائية لسطح الأسنان مقارنةً بمجموعة أطقم الأسنان التقليدية بعد ستة أشهر، واثنى عشر شهرًا، كما أظهرت كلتا المجموعتين فرقًا غير ذي دلالة إحصائية في متوسط قوى الإطباق فورا التركيب. وبعد ستة أشهر كان هناك فرق كبير إحصائيًا بين المجموعتين وأيضًا بعد اثنى عشر شهرًا كان هناك فرق كبير بين المجموعتين. فيما يتعلق برضا المرضى، كان هناك فرق ضئيل بين المجموعتين. ومع ذلك، كان المرضى في مجموعة أطقم الأسنان التقليدية راضين بشكل كبير من حيث الجماليات والصوتيات مقارنة بمجموعة أطقم الأسنان المصممة رقميًا. ومن ناحية أخرى، أظهرت مجموعة أطقم الأسنان المصممة رقميًا رضا متفوقًا للمرضى فيما يتعلق بالثبات والاستقرار أثناء المضغ.

الاستنتاجات:

تبعا لحدود هذه الدراسة، بما في ذلك عدد المرضى والفاصل الزمني، يمكن الاستنتاج أن: 1- أطقم الأسنان المصنوعة بالتقنيات التقليدية تحافظ على تآكل سطح الأسنان بعد عام واحد من إدخال طقم الأسنان مقارنة بأطقم الأسنان المصنوعة رقميًا. 2- أطقم الأسنان المصنوعة رقميًا توزع قوة الإطباق بشكل إيجابي مقارنة بأطقم الأسنان المصنوعة تقليديًا. 3- تقنيات صناعة أطقم الأسنان ليس لها تأثير على رضا المرضى.

المشرفون

أ. د/ أحمد علي عبدالرحمن حبيب

أستاذ الاستعاضة الصناعية

قسم الاستعاضة الصناعية

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كلية طب الأسنان - جامعة المنصورة

جامعة المنصورة
كلية طب الأسنان
قسم الاستعاضة الصناعية

تقييم التقنية الرقمية مقابل التقنية التقليدية لصناعة الأطقم الكاملة المستبقاة على غرسات للفك السفلي

رسالة علميه

مقدم لكلية طب الأسنان - جامعة المنصورة
كجزء من متطلبات الحصول على درجة الدكتوراة في الاستعاضة الصناعية

مقدم من

عبدالسلام عوض علي

بكالوريوس طب وجراحة الفم والأسنان
جامعة بنغازى ٢٠٠٩
ماجستير الأستعاضة في طب الأسنان
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٢٠٢٥