INTRODUCTION

With the advancement of the digital dentistry over the last years, it becomes so important to evaluate all the computer aided design/computer aided manufacturing (CAD/CAM) devices.

Various intra-oral scanners have been introduced in the market and CEREC (Dentsply Sirona, Bensheim, Germany) was the first intraoral scanner to be commercialized in the dental market and since then a large number of intraoral scanners have appeared with different technologies aiming for capturing image with a high resolution and accuracy.

With the increase rhythm of life and the increased awareness and the esthetic demand and the high expectation from both patients and dentists, also the development of CAD/CAM strategies in the production of restorations with high performance and optimal quality from new biocompatible materials, impression making of tooth preparation become essentially digitized since the fabrication of CAD/CAM based dental prosthesis requires a digital model.

The success rate of prosthesis relies on several factors, an accurate impression is one of the most important factor to ensure a proper restoration from a functional and esthetic point of view.

Conventional impression was used to be the only solution for capturing intra oral data and transfer it to the laboratory where all the conventional steps were performed starting from disinfecting the impression to pouring, casting, investing down to fabrication of the restoration.

The digital process of fabrication of dental restoration will eliminate the drawbacks produced by the conventional impression such as the risk of storage and damage, the inconvenience and inappreciation regarding the patient, the prolonged overall treatment time and the risk of contamination.

Studying the accuracy of the intraoral scanners has a fundamental role in developing the digital dentistry. The accuracy of impression is described as trueness and precision. Trueness is the ability of measurements matching the real image. Precision is the ability of measurements to be constantly repeated [1].

Trueness is achieved by capturing the same object using a powerful device with high level of accuracy and obtain a reference model in order to evaluate the deviation between the 2 measurements by their superimposition.

And precision is evaluated through superimposition of the scans obtained from the same intraoral scanner [2].

The superimposition are performed by a reverse engineering and 3D analysis software.

In our study the effect of different preparation designs on the trueness and precision of different intraoral scanner were evaluated. Different designs of preparations were performed to compare between them regarding the accuracy of the intraoral scanners also for the same preparation alteration in the design to reach the ideal preparation suitable for the digital scanning and optimize the accuracy of the intraoral devices. Also evaluate the accuracy in relation to the complexity of the scan and compare between the different intraoral scanners.

REVIEW OF LITERATURE

1. Impression

Dental impressions provide the foundation for all the restorative treatments. They are used to get an imprint of an intraoral situation on an extra-oral physical model. These dental impression provide a wide range of application ranging from models used for treatment planning or for patient communication to get master casts for the production of the final restoration. However, achieving impression with high accuracy can present a lot of challenges regarding to techniques and materials.

In order to receive that impression there are different ways to get it either by a conventional or digital approach.

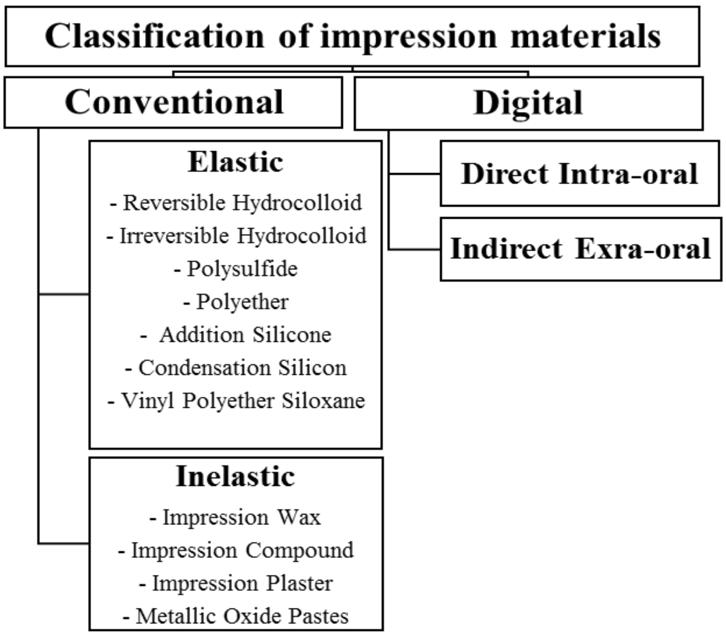

Figure 1: Classification of Impression Materials

1.1 Conventional impressions

1.1.1 History

In the middle of the seventeenth century, early references to making impressions in wax to reproduce parts of jaws and teeth were recorded by **Gottfried Purman**, A German military surgeon. Then, in the eighteenth century, reports were of an impression technique that is involving pressing a piece of ivory or bone on the oral tissues that were painted by material of coloring and then at the chairside carving out the fitting surface. In 1756 **Philip Pfaff** was the first to make an impression with 2 pieces of wax of an edntelous jaw and then join them to make a cast using plaster of Paris[3].

Other impression materials used were impression compound and zinc oxide eugenol impression paste, although their applications were very limited because of their inability to surpass undercuts without fracturing or distorting. Reversible hydrocolloids were introduced in 1925, followed by the irreversible hydrocolloids in 1941. [4]

The main disadvantage of hydrocolloids is shrinkage caused by water loss, leading to inaccuracy.

In 1953, polysulfide impression material was used along with condensation reaction silicones, but they both show a significant shrinkage over a period of hours, mainly because of the late evaporation of low-molecular-weight by-products.[5] In the late 1960s, polyether was proposed to be an alternative polymer because of its improved mechanical properties and low shrinkage.[5]

In the 1970s, polyvinyl siloxane (PVS) appeared in the market and became very popular, mainly because of its high dimensional stability.

1.1.2 Classification of impression materials

Impression materials can be classified according to their composition, setting properties, and setting reactions, but a commonly used system is based on the properties after the material has set

- Irreversible hydrocolloids (Alginate)

Alginate impression materials are used for full-arch impressions. Being inexpensive and easy to use it is popular for less critical applications e.g. study models and opposing casts[6].

They can also be used for impression of partial removable denture prostheses. The hydrophilic nature of the material allows it to be used in the presence of saliva and blood with a moderate ability to reproduce details. These materials have two major disadvantages. Firstly, very poor dimensional stability because of the ready loss or imbibition of water on standing in dry or wet environments respectively. Secondly, low tear resistance which can be a real problem when attempting to record the gingival sulcus so it can be poured once.[6] This material is flexible and easy to remove from the mouth compared with other materials if they flow into undercuts. They are easy to mix and easy to use with sufficient setting time to be handled and placed in the oral cavity.[7]

- Polyethers

A popular polyether impression material, Impregum (Espe GmbH, Germany), was the first elastomer introduced in the late 1970s.it was developed specifically for use in dentistry. It was initially available only in a single ‘regular’ viscosity, slight modification of the viscosity with the use of a diluent is possible. More recently a heavy light bodied system has been intoduced (Permadyne, Espe GMbH, Germany).[6]. The setting reaction for these materials is through a cationic polymerization with no by-product formation by opening of the reactive ethylene imine terminal rings to unite molecules. These material are hydrophilic so moisture control can be more forgivable. Also gypsum casts are made more easily because of their good wetting properties [8]. The new polyether impression materials are slightly more flexible than the older materials, making them easier to remove from the mouth.[9] Because of the material absorbing water nature, the impression should not be submerged in water for a long period of time because it could lead to distortion.it should therefore be stored dry. it can be used as a single-phase material or with a syringe-and-tray technique. The most popular method for dispensing this material is with the aid of a motorized mixing unit. [4]

-Silicones

Silicone impression materials are classified according to their method of polymerization on setting, to type I or condensation curing silicones and type II addition curing. silicones. Silicone rubbers are available in a similar range of viscosities to the polysulphides (i.e. light, medium and heavy). However, the range is supplemented by an added fourth viscosity; a very high viscosity or ‘putty’ material. The high filler loading of the putty was initially introduced to reduce the effects of polymerization shrinkage. The putty is combined commonly with a low viscosity silicone when recording the impressions, a procedure known a ‘putty-wash technique’. Condensation curing silicones were introduced to dentistry in the early 1960s. As like the polysulphides, the setting reaction produces a by-product volatile, but with type I silicones it is ethyl alcohol, not water. Loss of the by-product leads to measurable weight loss which is accompanied by shrinkage of the impression material on storage.[6]

-Polyvinyl siloxanes

The chemical reaction for polyvinyl siloxane (PVS or addition silicone) involves a base paste containing hydrosilane-terminated molecules reacting with an accelerator paste containing siloxane oligomers with vinyl end groups and a platinum catalyst. Although there is no formation of by-product, there is usually a secondary reaction that can release hydrogen in the presence of hydroxyl groups, commonly found in impurities from the oligomerization reaction of the siloxane molecule. It is therefore recommended to wait 60 minutes at least before pouring a PVS impression, although some manufacturers claim that the impressin can be poured immediately[8]. PVS impression material is claimed to be one of the most favored impression materials in dentistry because of its excellent properties and availability in many different viscosities that range from extralight body to putty consistency. Impressions made from this material highly produce great detail reproduction and can be poured multiple times because of their high tear strength and high elastic recovery. Caution should be taken to avoid contact of the material with latex gloves or latex rubber dams, which may leave a sulfur or sulfur compound that inhibits polymerization of the material. Moreover, gingival retraction which are soaked cords containing sulfur may also contribute to the inhibition.[10]

-Vinyl siloxaneether (Vinyl polyether siloxane)

A new impression material that combines the properties of polyether and PVS, vinyl siloxanether or vinyl polyether siloxane, was firslty introduced in the dental market in 2009 (Identium, Kettenbach Co, Eschenburg, Germany).[11] This material has been reported to combine the ease of removal of PVS with the hydrophilicity (wetting properties) of polyether[12] making it a very promising material for difficult situations in which moisture control issues are present, such as deep, narrow gingival crevices. However,the literature on accuracy of this new material is still under research.[13]

-Hydrophilic Polyvinyl Siloxane

Traditionally, PVS is a hydrophobic material in order to obtain a clinically acceptable impression a proper moisture control is of paramount importance. Many newer PVS impression materials have been claimed as hydrophilic, suggesting that they can perform adequately under wet or moist conditions. These products contain intrinsic surfactants that facilitate the pouring process with gypsum materials and improve their wettability. However, so-called hydrophilic PVS seems to remain hydrophobic when it is still in the unpolymerized state liquid and its wetting abilities are compromised in the presence of moisture. As a result, their surface detail reproduction is inconsistent when moisture control is not maintained.[8,7,14]

1.1.3 Disinfection of conventional impressions

Dental impressions are exposed to saliva, blood, or both[15]; therefore, dental clinics and commercial laboratories need to follow coordinated strict protocols to eliminate the risks of crosscontamination.[16,17]. To maximize effectiveness, disinfection should take place immediately when the impression is removed from the mouth[17]. Over the past 25 years, numerous reports have studied the effect of disinfection procedures on dimensional stability and the surface properties of dental impression materials[18,19]. These studies revealed that disinfection procedures do not have a clinically significant effect on impression accuracy and/or quality. Disinfection protocols include 2 steps. The first step consists of rinsing the impression with tap water immediately after removal from the patient's mouth. This process significantly reduces the number of blood-borne pathogens that can be transferred to the stone casts. The second step consists of spraying the impression with an appropriate disinfecting agent or immersing it into a chemical solution for a specific amount of time. Extra care should be taken when disinfecting polyether or water-based materials, because extended immersion times (>30 minutes) can have a negative impact on impression quality since they are affected by moisture[7,] In general, prolonged disinfection times should be avoided because of their adverse effects on material wettability and contact angle.

1.1.4 The challenges of the conventional impression

The accuracy of the conventional impression depends on the materials themselves[20,21,22], impression tray types[23], and impression techniques[24]. Each step in the process introduces material error and/or potential human error [25].Also there is some variations in impressions and the resulting master casts, depending on the technique and material used by the dental operator[26]. The accuracy of master casts has been an important subject of numerous research projects, and is dependent on so many items, including the vacuum versus hand mixing[27], water/powder ratio, and the type of dental stone and its compatibility with impression material used[28].

Also there are challenges posed by plaster models that are made from conventional impressions, include risk of damage or breakage, the burden of storage, and the difficulties in sharing the data with other clinicians that can be involved in the patients care. [29]

Hence the transformation of the clinical situation into a three-dimensional data will eliminate these drawbacks in the production process of dental restorations. It can be achieved by direct or indirect digitalization.

2. Digital impression

Digital impressions and scanning systems were introduced in dentistry in the mid-1980s. it was predicted that most of the dentists in the U.S. and Europe would be using digital scanners for taking impressions within the next decade [29]

Intraoral digital impression making has evolved in the last years beyond single tooth preparations and sextant scanning to include the ability to record complete arches. Intraoral digital scanners allow the dentist to capture the surface of the teeth, implant scanbodies, and soft tissues in 3 dimensions, enabling instant evaluation of the digital cast and instant communication to the laboratory, chairside milling unit or 3 dimensional printer [30].

Emir Yuzbasioglu et al in 2014 [29] investigated 24 patients who had no previous experience with either conventional or digital impression. Conventional impressions of both dental arches were taken with a polyether impression material (Impregum, 3 M ESPE), and bite registrations were made with polysiloxane bite registration material (Futar D, Kettenbach). Two weeks later, digital impressions and bite scans were performed using an intra-oral scanner (CEREC Omnicam, Dentsply Sirona, Bensheim, Germany). Immediately after the impressions were made, the subjects' attitudes, preferences and perceptions towards impression techniques were evaluated using a standardized questionnaire. The perceived source of stress was evaluated using the State-Trait Anxiety Scale. Processing steps of the impression techniques (tray selection, working time etc.) were recorded in seconds. And it was reported that digital impressions resulted in a more time-efficient technique than conventional impressions. Patients preferred the digital impression technique rather than conventional techniques.

Ahlholm et al in 2016 [31] stated in their review evaluating the evidence of possible benefits and accuracy of digital impression techniques versus conventional impression techniques that digital impression accuracy is at the same level as conventional impression methods in fabrication of crowns and short fixed dental prostheses (FDPs). For fabrication of implant-supported crowns and FDPs, digital impression accuracy is clinically acceptable. In full-arch impressions, conventional impression methods resulted in better accuracy compared to digital impressions.

Chochlidakis et al in 2016 [32] also published a systematic review comparing the marginal and internal fit of fixed dental restorations fabricated with digital techniques to those fabricated using conventional impression techniques and determining the effect of different variables on the accuracy of fit and reported that the fabrication technique, the type of restoration, and the impression material had no effect on misfit values

(P>.05), whereas die and restoration materials were statistically associated (P<.05) and the digital impression technique provided better marginal and internal fit of fixed restorations than conventional techniques did.

Santiago Berrendero et al in 2018 [33] compared the clinical aspects of all-ceramic crowns fabricated from conventional and digital impressions and reported that in most cases and in a significant way, the digital crowns had better clinical conditions according to both evaluators. The digital crowns were statistically superior for the interproximal contact points and marginal fit. For the variables occlusal contacts and primary retention, no difference between the two groups was observed.

Yuki Tomita et al in 2018 [34] compared the accuracy of digital models generated by desktop-scanning of conventional impression/plaster models versus intraoral scanning of dental epoxy models by linear distance measurements and it was reported that Intraoral scanning may be more accurate compared to conventional impression/plaster model methods.

So for obtaining digital impression, it can be through direct or indirect acquisition techniques.

The indirect technique involve the use of extra oral scanners and the direct technique involve the use intraoral scanners.

Indirect, extraoral digitalization starts with a conventional impression that is processed to a gypsum cast and then digitalized in the dental laboratory using laser scanning or computed tomographic imaging or scanning the impression itself [35]

2.1 Intraoral scanners

The abbreviation "CAD/CAM" denotes computer-aided design and computer-aided manufacturing. The establishment of CAD/CAM-technology has been the game changer since the 1980s for the production of tooth-borne and implant-supported monolithic fixed dental prostheses (FDP) primary by means of digitally on-screen designing with dental software applications, and secondary computer-assisted production with rapid prototyping procedures, such as milling or 3D–printing, in a virtual environment without any physical model production [36]

The brand name "CEREC" came on the market in 1987, it was the first CAD/CAM system used in dentists' offices. It was initially designed for the manufacture of esthetic ceramic restorations. Over the years, the system has developed into the fourth version of the hardware, enabling the manufacture of different dental restorations such as inlay and onlay fillings, crowns, laminates, FDPs and even implants [31].

Moreover, CAD/ CAM workflow permits utilizing other materials, which were previously happened to be technically too challenging and uneconomical such as high-performance ceramics/zirconia [37,38,39]

Intraoral scanners (IOS) are powerful devices used for optical impressions taking, and are able to collect information and transmitting them to the computer with the shape and size of the dental arches (or the position of dental implants) through the emission of a light beam[40,41]. In fact, they project a light or beam grid (structured light or laser) onto the tooth surface (or implant scanbodies), and capture back, through high-resolution cameras, the distortion that such a beam or grid undergoes when they hit these structures[40,41]. Then the information collected by these cameras is processed by powerful software that reconstructs the three dimensional (3D) model of the desired structures[41,42]. In particular, from the creation of a "cloud of points" a polygonal mesh is derived, representing the resultant scanned object; the scan is then processed to obtain the final 3D model [41,42].The conventional physical detection of impression with trays and materials (alginates, silicones, polyethers) represents a moment of discomfort for the patient[29,43]; this is particularly the case with sensitive individuals, for example those with a strong gag reflex[44]. In addition, it is difficult for the clinician, especially in the case of technically complex impressions (for example for the fabrication of long-span implant-supported reconstructions) to get an accurate imprint from a conventional impression [43,45].

2.1.1 The advantages of Intraoral scanners (IOS)

The optical impression with IOS solves a lot of the previous problems associated with conventional impressions: it is well tolerated by the patient, since it does not require the use of conventional materials, and is technically easier for the clinicians since it doesn’t involve many steps[29,46,47]. It eliminates the need for materials and impression trays, which are often unwelcome to the patient [48,49,50] Patients tend to prefer optical impressions rather than conventional impressions, as the literature reported it [29,51].

The use of an IOS allows the determination of the quality of the impression on the spot; virtual 3D models of patients are obtained, which can be saved on computer without physically pouring a plaster model[41,45,52]. This saves time and space, Several studies have shown that optical impressions are time-efficient, as they enable reduction of the working times (and therefore costs) when compared to conventional impressions [45,29,48].

Despite the recent technological advancements in IOS, with the latest devices introduced in the market enabling the capture of a full-arch scan in less than 3 min, it does not appear that the major differences in time efficiency stem from the act of making an impression itself (a full arch scan may take 3–5 min, similar to that required for conventional impressions), but rather from the time saved afterwards, during all subsequent steps [53,54,55].

In fact, with optical impressions, there is no need to pour stone casts and obtain physical plaster model [31] it is possible to e-mail directly the 3D virtual models (proprietary or STL files) of the patient to the dental laboratory without the need to deliver anything via regular mail. This enables saving a considerable amount of money and time during the working year[32].

For dental clinics prepared to design and manufacture of chair-side prosthetic restorations, the files captured during optical impressions will be imported into computer assisted design (CAD) software; once the design of the restoration is completed, the files can be transferred to computer assisted manufacturing (CAM) software and put into the milling machine. The restorations (in different materials) thus obtained will be handeled and ready for clinical application[56,53,49].

The clinician can save money each year on the purchase of impression materials, the fabrication of custom trays, and on casting of plaster models; it is easy to store virtual models of patients without dedicating them a space in the clinic. the clinician can use it as a powerful