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COMPARISON OF THE ACCURACY OF INTRAORAL SCANNING SYSTEMS WITH CONVENTIONAL IMPRESSION IN FULL DENTATE PATIENT

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Imadettin ALSAYED

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III. Abbreviations and Symbols

3D: Three-Dimensional

ANOVA: Analysis of variance

ASTM: American Society for Testing and Materials.

CAD: Computer-aided design.

CAM: Computer aided manufacturing.

CEREC: Chairside Economical Restoration of Esthetic Ceramics or CEramic REConstruction.

DWOS: Dental Wings software.

FDPs: fixed dental prostheses.

Lava C.O.S: Lava Chairside Oral Scanner.

LSD : least significant difference

P: probability value

SD: Standard deviation

Sig: significance

SLA: Stereolithographic.

SPSS: Statistical Package for the Social Sciences

STL: STereo-**L**ithography or Standard Triangle Language or Standard Tessellation Language.

µm: micron

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1. TURKISH SUMMARY

Tüm Dişleri Mevcut Hastalarda Konvansiyonel Ölçü Ve İntraoral Dijital Taramanın Netliğinin Karşılaştırılması.

Öğrencinin Adı: Imadettin Alsayed
Danışmanı: Umut Aslan
Anabilim Dalı: Protetik Diş Tedavisi Anabilim Dalı

Amaç: Son senelerde, direkt dijitalizasyon için farklı intraoral tarama sistemleri ortaya çıktı. Ancak bu tarayıcılarının netliği değişkendir, ve hakkındaki bilgiler yetersizdir. Bu çalışmanın amacı iki farklı intraoral tarama sisteminin, alt ve üst çene arasındaki netliğinin farkının karşılaştırılmasıdır.

Materyal ve Method: 10 adet eksik dişi bulunmayan hastanın her birinden bir adet PVS (Elite HD+, Zhermack SpA, Italy) materyali ile ölçü alındı, ve 3 adet alt-üst çene taraması CEREC OC(Sirona Dental Systems, Sirona, Bensheim, Germany) ve Straumann CARES IOS(Intra oral Scanner, Basel, Switzerland) ile yapıldı. Konvansiyonel ölçü döküldü ve elde edilen alçı model taratılarak referans model olarak netlik ve doğruluk kıyaslamasında kullanıldı. Netlik değerlendirilmesindeki deviasyonlar diğer ölçülerin birbiri üzerine çakıştırılması metodu ile gözlemlendi. Dijital ölçü dosyaları STL formatına dönüşütürülerek (Geomagic Control; 3D Systems. USA) ile işlendi ve analiz edildi**.**

Bulgular: Doğruluk değerleri , CEREC OC için üst çene 99,88±42, alt çene için, 82,6±26,81 μm. CARES IOS için üst çene için 105,53±25,49 μm, alt çene için 109,56±36,84 μm dur. Iki sistem arasındaki fark istatiksel olarak anlamlı değildir ($P>0.05$). Netliğin farkı istatiksel olarak anlamalıdır ($P<0.05$), CEREC OC alt ve üst çenede daha yüksek değerler gösterdi.

Sonuç: CEREC OC netlik olarak CARES IOS sisteminden daha üstün bulunurken doğruluk seviyesi her iki sistemde de benzerdir. Alt ve üst çeneler arasında her iki sistemde istatistiksel olarak anlamlı fark bulunmamıştır.

Anahtar kelimeler: Intraoral tarama, STL dosya, Netlik, CAD/CAM

2. ENGLISH SUMMARY

Comparison of The Accuracy of Intraoral Scanning Systems with Conventional Impression in Full Dentate Patient.

Imadettin ALSAYED, Dr. Öğr Üyesi. Umut ASLAN, Department of Prosthodontics

Aim: Over the last years, different intraoral scanning systems for direct digitalization have been introduced to the dental market. However, the accuracy of these scanners is variable, and little information is available. The aim of this in vivo study was to compare the accuracy of two intraoral scanning systems and the difference between upper and lower jaw on the accuracy.

Material and Method: 10 patients with full dentition received one conventional impression with polyvinyl siloxane (PVS) (Elite HD+, Zhermack SpA, Italy) and three scans with CEREC OC (Sirona Dental Systems, Sirona, Bensheim, Germany) and Straumann CARES IOS (Intra oral Scanner, Basel, Switzerland) for upper and lower jaw. The conventional impresions were poured and the casts made from it were scanned and used as the reference model to evaluate precision and trueness of intraoral scanning virtual models provided by each system. Impression files were converted to STL files and processed and analyzed using (Geomagic Control; Geomagic, Morrisville, USA).

Results: The trueness value was 99,88±42,56 μm in upper jaw and 82,6±26,81 μm in lower jaw for CEREC OC, and 105,53±25,49 μm in upper jaw, and 109,56±36,84 μm in lower jaw for CARES IOS. The differences between two systems were not statistically significant ($P>0.05$), but statistically significant difference was found in the precision ($P<0.05$). CEREC OC showed higher value in both upper and lower jaws.

Conclusions: CEREC OC was more precise than CARES IOS and at the similar level of trueness. No statistically significant difference was found between upper and lower jaws in both systems.

Key Words: Intraoral scanning, STL files, Accuracy, CAD/CAM

3. INTRODUCTION AND AIM

Dental impressions have been used to achieve impressions of the intraoral structures, and then impression is poured to get the cast, on which the restorations are constructed. Impressions are highly used in dentistry field, starting from making casts for diagnosing to making final casts to fabricate the definitive restorations (Hamalian TA et al.,2011).

In the conventional technique, a cast is made after an impression has been taken with a tray filled with an impression material. Impressions that are taken with irreversible hydrocolloids must be poured quickly, because delayed pouring negatively affects their accuracy and dimensional stability. Elastomeric impression materials available for final impressions are vinyl siloxanether, vinylpolysiloxane, silicone, and polyether. These materials are the most popular methods of transferring details from the patient technician when indirect restorations are made (Wadhwani CP et al.,2005).

3.1. Polyvinyl Siloxane Conventional Impression Material

Polyvinyl siloxane materials (PVS) are a modification of the original condensation silicones. Both are based on the polydimethyl siloxane polymer, however the presence of differing terminal groups accounts for their different curing reactions. these materials are materials used for dental and gingiva impressions. It enables capturing highly accurate impressions that resist distortion and tearing when being removed. PVS impressions allow better fitting restorations. The material allows a range of viscosities from light body, which may be administered with a syringe, to heavy body and putty materials often used for bite impressions. Depending on the restoration or impression needed, various-viscosity PVS materials may be used. Set time vary depending on viscosity and brand, but often ranges between 2 to 5 minutes.

PVS (polyvinyl siloxanes) is one of the frequently used impression materials in dentistry; it is proved to insure accurate impression of the oral cavity (Vecsei et al., 2016).

With the increasing application of digital impression systems, developed in the 1980s, it became possible to eliminate the physical casts which used in conventional systems. In digital system, the intraoral structures are digitally recorded with an intraoral 3D acquisition device, and the obtained details allow the computer to generate a virtual model. Final restorations are made depending on this virtual model. A growing number of fixed prostheses have been fabricated using intraoral digital impression methods which have now an important role in digitization process of prosthodontics (Galhano GA et al., 2012; Hamalian TA et al.,2011; Wadhwani CP et al., 2005).

The digital impression method has a lot of advantages, for example, enhancement of patient acceptance, reduction in terms of deformation of impression materials, the opportunity of providing enhanced 3D preview of tooth preparations, and potential cost- and time- efficiency (Christensen GJ,2009; Yuzbasioglu et al., 2014).

Computer-aided design and computer aided manufacturing (CAD/CAM) have been used in the production of restorations, mostly ceramic crowns and fixed dental prostheses (FDPs) since the 1980s (Mormann., 2006). Some published articles have referred that dental prostheses made with intraoral digital impressions have showed outstanding qualities over those from conventional impressions in many aspects (Syreket al., 2010).

Many CAD/CAM systems are in the market to design and produce restorations regarding two ways to fabricate the virtual model:

- Extra-oral scanning: in such cases, a gypsum cast is produced with the silicone impression and sent for extra-oral scanning where the gypsum cast is placed on platform of the extra-oral scanner.
- Intraoral scanning: the impression is done directly from patient mouth by intraoral scanner (Seelbach et al.,2013).

Although the precision of extraoral scanning is sufficient, the intraoral outline expressive process of a conventional impression is difficult to perfectly refabricate because of the distortion of impression materials and plaster. Thus, the deficient accuracy of plaster casts is not optimal for completing CAD/CAM procedures. In contrast, errors can be averted using direct intraoral digital impressions more than the conventional impressions.

In Addition to saving time spent on making conventional impressions and plaster models and decreasing the cost of materials. Recent advances in the field of intraoral digital impression provide major enhancements. During the past two decades, many prominent intraoral scanning systems were produced. Recently, an growing number of fixed prostheses are now fabricated with intraoral digital impressions, which have become a crucial piece in the process of digitization of prosthodontics (Galhano et al,2012).

3.2. Aim of Study

The aim of this in vivo study is to compare the accuracy (trueness, precision) of a powder-free, continuous imaging impression system (CEREC OC) and Multi- scan Imaging system with powder (STRAUMANN CARES IOS) to determine the more accurate system and the difference between upper and lower jaw on accuracy of intraoral scanning.

3.3. Research Hypothesis

The null hypothesis was (1) because of requiring a layer of powder, the inhomogeneous powder thickness may slightly affect the accuracy comparing with powder free system. (2) Significant differences between upper and lower jaws impressions can be found.

4. GENERAL INFORMATION

4.1. CAD CAM Components

CAD/CAM systems consist of three main parts:

1. A data acquisition unit, which gather the data from the area of prepared teeth and adjoining structures and then transform them to virtual impressions (an optical impression is formed during that directly or indirectly).
2. Software for designing virtual restorations according to the virtual impressions and setting up all the milling properties.
3. A computerized milling machine for fabricating restorations with hard blocks which are made of different restoration materials.

The CAD stage is done with the acquisition unit and the software, on the other hand the third part is in charge of the CAM stage (Galhano et al,2012).

4.2. Data Acquisition

The first step of gathering data is scanning the prepared tooth and convert the information into 3D digital data which will later help to design and fabricate the CAD/CAM dental restoration (Beuer et al., 2008c).

Dental CAD/CAM scanners are classified in two groups: **laboratory scanners** (which are usually used with conventional impressions and stone models) and **intraoral scanners** (digital impression) (Fuster-Torres et al., 2009).

1) **Laboratory scanners** Laboratory scanners can gather information from the plaster model (Miyazaki et al., 2009) or directly from the impression (according to the system). Fabricating time in highly reduced when direct scan is made for the impression because there's no need for pouring and trimming. Still, the procedure of scanning dental impressions is a challenging method, because it is difficult for the scanner light to reach deep points inside the impression.

3shape D700 (Copenhagen, Denmark)

The D700 3D is a laser scanning device which is part of 3Shape's Dental System 2009.

D700 refers to the coming generation of scanning technology and an apex of 3Shape's scanning practice. This method provides the overall indication and treatment more than any other scanner to reach improved clinical results. D700 also provides advanced quality impression of scanning that is considered a huge step in digital dentistry and better productivity upgraded process with remarkable benefits on the long term of investments.

D700 employs a market unique 2-camera setup and 3-axis motion system. In addition to the advantage of impression scanning, this makes D700 fast when scanning full cast dental plaster models. Considering the advanced technology setup in D700, the speed of the process does not affect the quality of production as D700 guarantees high quality scanning results and excellent precision in details resolution and dimensions.

The D700 also covers an outstanding number of unique scan indications including impression scanning, post & core, 14 unit bridges, articulated antagonist model, deep inlays, pre-preparation model aligned to preparation model implant position, and orientation detection, wax-up customized abutment, and wax-up implant bridges for copy milling.

2) **Intra oral scanners** gather the data of the teeth preparation directly from the oral cavity, which allows instant designing and fabricating of the dental restoration (Mattiola et al., 1995; Reich et al., 2005b). Intra oral scanners are very precise scdigital impression(Patzelt et al., 2014b), this method helps to reduce dental clinical procedures, obtain the impression and lower the level of discomfort and the feeling of gagging for the patient (Christensen, 2009; Logozzo et al., 2014).

The intraoral cameras can be divided into two categories (Zimmermann et al., 2015; Abdel-Azim et al., 2015):

(a) Single image cameras this type can take single image of the dentition. The iTero (Align Technology), PlanScan (Plan- meca), CS 3500 (Carestream Dental LLC), and Trios (3 shape) cameras are individual image cameras that can take approximately three teeth in one image. To scan bigger portions of the dentition, consecutive single overlapped images are recorded which the program can collect into a larger 3D virtual model. There are different angles to position the camera in order to have quality and precise imaging of the dentition especially the data under the height of contour that is invisible to the camera only if the occlusal view was recorded. Invisible portions which are in the overlapped areas would then be extrapolated by the software to fill in the missing data in the virtual mode.

(b) Video cameras this type is used by the True Definition scanner (latest version of the Lava Chairside Oral Scanner, COS), Apollo DI (Sirona) and OmniCam (Sirona) systems.

4.3. CAD/CAM Classification

CAD/CAM systems are classified according to data sharing ability, scanning device and fabricating technique or milling process.

4.3.1. Depending on data sharing capacity

There are two types of CAD/CAM systems according to the data sharing capacity: closed and open. (Correia et al.,2006)

a) Closed systems provide all CAD/CAM steps, including data obtaining, virtual design, and restoration fabrication. All the procedures are included within the one system. Switching between systems is not possible.
b) Open systems permit the adoption of original digital files by other CAD software and CAM devices.

4.3.2. Depending on scanning device

There are two types of CAD/CAM systems according to their scanning device:

a) Chairside (In-office): many system alternatives come under this label: only the scanner (intra-oral, e.g. Lava C.O.S), scanner with designing software (e.g. E4D) or also all the components of the CAD/CAM system in the clinic (scanning device, designing software and milling device, e.g. CEREC system).

b) Dental laboratory: The impression is made in the clinic, then the remaining fabricating procedures (designing and milling) will take place in the laboratory. Laboratory should have either the laboratory scanner, designing software or the milling device, or the scanner and the designing software alone (Mantri and Bhasin, 2010).

4.3.3. Depending on milling process

This classification is divided into dry or wet. The milling procedure (wet or dry) is defined according to the type of the material used in milling (Beuer et al., 2008c).

a) **Dry milling:** Semi sintered zirconia oxide are basically used in dry processing milling technique, this has many advantages: Preventing the dry zirconia oxide from absorbing moisture so it can be sintered instantly, decreasing the wear of equipment during milling process and this will lower the cost and makes the milling device cheaper. Furthermore, there are new presented materials that can also be dry milled such as resin. Lava™ CNC 500 (3M ESPE), Zeno 4030 (Wieland-Imes, Ivoclar Vivadent) and Cercon brain are examples of dry milling devices.

b) Wet processing: complete sintered glass ceramics and metals are used with milling machines. In order to conserve the diamond or carbide cutting burs against overheating while processing the restoration, a cooling liquid should be used. Wet processing devices are usually compatible with complete sintered ceramic, so the material is milled to the accurate size and form without following shrinkage as the sintering process is done. Examples of wet process milling devices include Zeno 8060 (Wieland-Imes), Everest (KaVo), inLab(Sirona)

4.3.4. Depending on fabricating final restoration

To fabricate the final restoration, there are two methods, subtractive technique, which is the most common technique, and the additive one.

a) **The subtractive processing technique** is basically about mechanically cutting the material (milling) to reach the optimal form. Using this method helps with producing complex forms with a minimum time of fabrication (van Noort, 2012). On the other hand, this method has a disadvantage of over consuming because the material which removed during the process cannot be used again. For example of the subtractive technique, zirconia blocks (Giordano and McLaren, 2010) and the Lava (3M, ESPS) milling machine. In order to decrease the cost of the process, many manufacturers have changed to the additive method.

b) The additive manufacturing technique is the process of joining materials to make objects from 3D model data, usually layer upon layer, as the American Society for Testing and Materials (ASTM) describes it. During this technique, the works is formed out of series of cross sectional layers, which are added on top of each other to finally reach the three dimensional object (model). This method helps to limit the waste of material. It was originally called as Rapid Prototyping, and was presented in the 1980s to make models and prototypes of items. Fabricating complete scale models is possible today thanks to the additive manufacturing technique, which helps in adjusting and customizing the items before fabricating the final form (Stoker et al., 1992; Kernan and Wimsatt Iii, 2000; Cohen et al., 2009; van Noort, 2012). The example of the additive technique is the production of resin Stereolithographic (STL) models from computer aided design via 3D printer.

4.4. File Format

The file format created by CAD software is either Standard Tessellation Language or Standard Triangle Language or **ST**ereo-**L**ithography files (STL). The STL files are classified as open files which are original to the CAD software and that makes it accessible for all of the companies to fabricate a CAM machine that is compatible with most of available CAD software. Some file formats are only compatible with the milling device of the same company (Mehl et al., 1997); but there is a tendency towards the open access formats in order to make it easily accessible to wider range of companies and materials (van Noort, 2012). Finally, after designing the 3D dental restoration, it is sent to the milling machine as a digital format file to be milled and fabricated according to produce the final dental restoration.

4.5. CAD

Dental restorations are designed with special software with 3D technology and each company has its own one (Beuer et al., 2008c). The CAD software is prepared with a library that includes variety of designs for crowns and bridge frameworks, full anatomical crowns and bridges, inlays and onlays. Recent developed software can produce even more types of dental restorations, such as implant abutments, removable partial denture frameworks, and orthodontic appliances. After sending the data to the CAD software, the laboratory procedures will start virtually after completing the job order (digital laboratory request). A virtual die will be initiated, then the die sectioning, and then the preparation finishing line should be marked and finally the design of the dental restoration. The CAD software will offer an initial form for the optimal restoration that fits the prepared tooth regarding the finishing line, opposing dentition and contact points and dentist can customize the restoration as well (cusps, fissures, etc.).

Formerly, manufacturers introduced closed software, which is only compatible with their own system and cannot be used with a different company. Recently, the companies begin to offer open source format files (software) that allows the use of scanning device with other CAD systems (Miyazaki et al., 2009).

4.6. CAM

Like in any other producing fields, Computer Aided Manufacturing in dental medicine is the leading procedure that will lead to the fabricating of the final restoration. The technology has become complicated concerning both the software and hardware. Recently, laboratories started to buy the newest technology available for milling and cutting dental materials as it is considered that it will decrease the working time and minimize the price (Beuer et al., 2008c; Lesson, 2014).

4.7. Materials Available for the Use with CAD /CAM

Many types of fixed (crowns, bridges, implant abutments, inlays and onlays) and removable (removable partial dentures) dental restorations in addition to orthodontic appliances can be fabricated using CAD/CAM technology.

Many different CAD/CAM systems are compatible with another types of materials. Silica-based ceramics, infiltrated ceramics and oxide high performance ceramics (Aluminum Oxide and Yttrium Stabilized Zirconium Oxide) are the most commonly used materials with CAD CAM technology nowadays (Beuer et al., 2008c). The materials are introduced in blocks and are mono-chromatic or poly chromatic (Baroudi and Ibraheem, 2015). In addition to ceramics, metals (titanium, titanium alloys and chrome cobalt alloys), waxes and resin materials can also be used with dental CAD/CAM systems (Beuer et al., 2008c).

4.8. Work Flow to Produce Dental Restorations

There are two methods to have the impression of the dental structures in terms in indirect restorations that will be made using CAD CAM technology. They are the digital impression or the conventional impression (Miyazaki et al., 2009).

The **conventional** method usually includes taking an elastomeric silicone impression to construct a working model. According to the kind of laboratory scanner used, the scan can be done on the elastomeric silicone impression itself or the gypsum model obtained by pouring of the impression (Beuer et al., 2008c). This is to gather all of the information required to design and produce the dental restoration.

Another way is done with is the **digital impression** which can be obtained using an intra oral scanner. The software will then merge the scanned prepared teeth with the opposing dentition on a virtual articulator depending on the digital occlusal record. Then the digital model is divided virtually to produce the working die. The obtained information is sent to a lab, which will prepare articulated STL working model. To have an accurate contact points and occlusion, the models preparation is a very essential procedure during the veneering step of the ceramic framework. (Beuer et al., 2008c).

Designing the dental restoration using the CAD software and producing the desired restoration are made with the same procedures whether the impression was made from scanning a stone model or from intra oral scanning. The final dental restoration can either be fabricated in the clinic when the milling device is available or the design may be sent to a production lab for constructing (Figure 1.9).

When the material (ceramic) is fully sintered no need for extra procedures other than finishing (e.g. veneering and glazing) the restoration; while in cases with semi-sintered zirconia, restoration needs to be sintered in the oven to be finished.

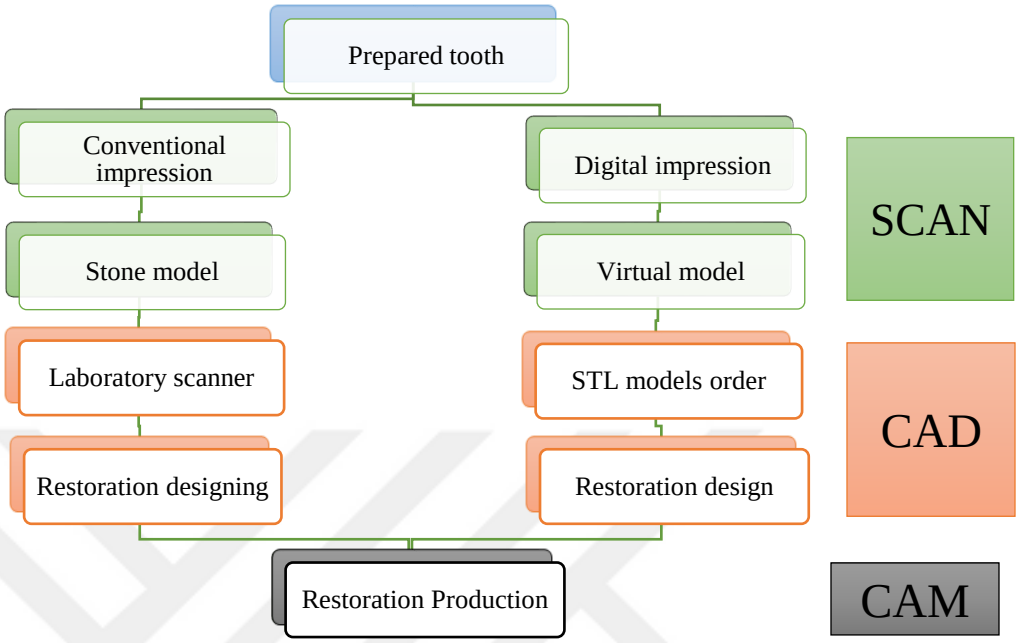
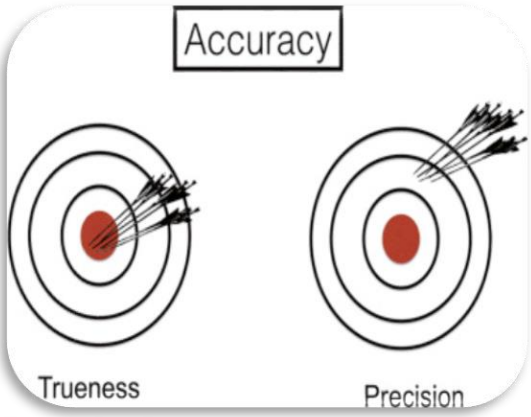


Figure 4.1. Work flow (conventional and digital) for fabricating a dental restoration using CAD/CAM technology.

4.9. Accuracy of Intraoral Digital Impression

Accuracy consists of trueness and precision (ISO 5725-1). Precision refers to how repeated measurements match each other. So, the scanner with higher precision indicates a more repeatable and regular scan. Trueness indicates how different are the scanned measurement from the real dimensions of the scanned structures. Therefore, the scanner with high trueness means that the scanner provide a result that is a match or close to the real dimensions of the scanned structure.



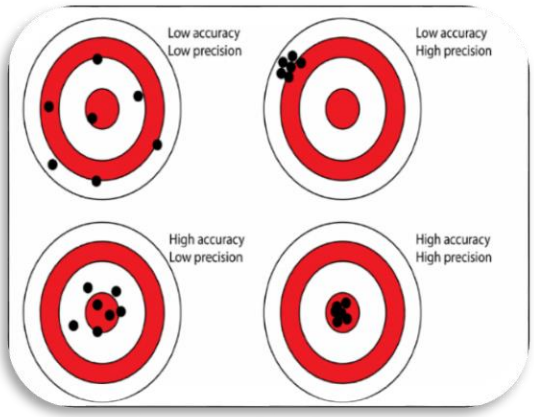


Figure 4.2. Components of accuracy **Figure 4.3.** Accuracy explained graphically

Most manufacturers do not publish the results of their devices' accuracy and do not mention the method they used to measure the accuracy (Vlaar and van der Zel, 2006); the accuracy is mostly decided in the following studies and researches carried out after the device is presented.

Quality of the standards in the company plays a major role in determining the accuracy of the dental scanners. Leading manufacturer's scanners use superior fabricating equipment and materials. Rough handling also affects the scanner hardware, which will leads to affect scanning accuracy when moving the device from one place to another. To avoid such problems, scanners can be re- examined after they are moved to another place and also if the place temperature is changed, and this must be scheduled work to maintain the quality results of the scanner. Some systems offer scanners with a calibration tool, with a known precision factor which is more than the scanner precision ability.

Another factor which has an impact on precision is the volume of the scanner. Bigger scanners usually have improved results due to their steadiness and their parts are automated which will limit any potential movement and subjective error while scanning the object (Hollenbeck et al., 2012).

Marginal and internal fitness are crucial standards to reach optimal FDPs and ceramic restorations. A precise impression is essential to construct an accurate restoration. (Syrek

et al., 2010) carried out an in vivo test to compare the adaptation of zirconia single crowns constructed from an intraoral digital impression with that from a conventional silicone impression. The experiment measured four surfaces (mesial, distal, buccal, and lingual) of each tooth. The median marginal gaps in the digital impression group were 50 μm for mesial, 55 μm in distal surface, 53 μm for buccal, and 51 μm for lingual. For the conventional impression category, the gaps were 69 μm for mesial, 70 μm for distal, 74 μm for buccal, and 67 μm for lingual. The total marginal gaps of digital and conventional impression categories were 49 μm and 71 μm, respectively. The research summarized that ceramic restorations constructed from a digital impression had more accurate fit than conventional impressions. It also showed more fitting interproximal contact for the digital category than the conventional one. The all-ceramic crowns produced from digital impressions revealed narrower marginal gaps than the ones from conventional impressions.

The results were mainly demonstrated by the difference in operation procedures: in the conventional category, plaster models are made of silicone impressions, while in the digital category; the restorations were customized and constructed directly from the digital data after scanning without making any physical model. Furthermore, the silicone impressions and plaster models might induce unavoidable complications from distortion. Thus, the crowns fabricated from the digital impression can reach higher quality of accuracy.

(Ender and Mehl, 2011) made an in vitro scanning test on complete arch to evaluate the accuracy of conventional and digital impressions, they confirmed the values to be 30.9 μm for CEREC Bluecam, 60.1 μm for Lava C.O.S., and 61.3 μm for a conventional impression. The authors determined that the accuracy of digital impressions was identical to that of conventional impressions, probably due to a powder coat spraying which is usually applied before both CEREC and Lava C.O.S. scanning process. Even if the software of the scanner could measure the thickness of powder coat spray to count it in the algorithm, the thickness of the powder varies between dentists, and cause a decrease in scanning accuracy (Da Costa JB et al., 2010).

4.10. Scan Speed and Productivity

Scan speed is a very crucial factor to decide on a scanner, the speed will affect the productivity of the dental laboratory and finalizing the process. In case of precision, there is no criteria to compare between scanners and no researches has been published from the manufacturers to compare them with their marketing claims. It is supposed that scanning duration takes from 30 seconds to few minutes (Hollenbeck et al., 2012).

Only the scan speed factor is not enough to indicate the abilities of the scanner in terms of productivity. An overall workflow needs to be examined, starting from creation of the operation, scanning, designing and finalizing with milling the dental restoration. When various systems are compared according to this point of view, this will result in large accomplishment differences. Usually, complete automated systems consume less time on the device and on the total scanning process. As previously mentioned, this will decrease complications caused by dentists. More time is needed when the system in run manually because many settings should be adjusted (camera brightness, die position, etc.).

The CAD software will also limit the forms of restoration that will be fabricated. Thus, it is more sufficient to get the scanner and the CAD software from the same company as the developer can apply more adjustments and this will provide more ideal workflow (Hollenbeck et al., 2012).

4.11. Advantages of CAD/CAM Technology

Nowadays, intraoral digital scanning systems have many advantages over conventional systems such as the digital impression, obtaining digital models and setting models on virtual articulators with the face bow. (Tariq and Alghazzawi, 2016).

4.11.1. Digital impression

1) Consume less operating time without the need for tray selection, distribution and setting of materials, disinfection, and sending of the impression to the technician.
2) Avoid the cost of impression materials, trays and shipment to the labrotory.
3) Obtianed digital information can be easily stored and used later when needed during the process of restoration construction.

4) Reducing many complications related with conventional impression materials including issues of the features of impression materials, inconvenient soft tissue handling, unsuitable tray selection, possibility of deformation of the impression before pouring ; the possibility of bubbles, tears, and distortion while taking impressions; loss of accuracy from wrong tray placement, incomplete bonding between dual phase impression materials, the change of dimentions of impression materials that happens in the time between taking impression and constrcution of the working model.
5) Enhancement of patient's comfort because the digital impression is mush faster process and does not need any trays and this will eliminate the gag reflex.
6) The ability to veiw scanned objects easily on a computer screen which helps the dentist to examine the preparation (intraocclusal distance, inappropriate margins, and axial reduction), and make instant adjustments to the preparation and/or retake the impression if needed before sending the file to the milling machine or a laboratory.

4.11.2. Digital models

1) Avoiding the shrinkage associated with polymerization of the impression material, disinfection of the impression, vacuum mixing, pouring an impression, wasted time waiting for the stone to set, expansion of the stone, in addition to the time-consuming steps to pour the base and pin models.
2) The digital models are accurately generated by ditching the dies digitally so that the inexactness of manual trimming is eliminated.
3) The final restoration is easily customized by the technician using the digital instructions. The software will cut and trim the digital dies and connect them with engaging parts which cannot shift during adjustment especially for the multi-unit prosthesis.
4) The technician cannot apply changes on the margins as can happen with a stone die without the need for solid model.

4.11.3. Virtual articulators and face bow phase

1) Decreasing the disturbance by the physical facebow.
2) Consumes less amount of time than applying the physical facebow.
3) Elimination of an interocclusal record, this can be conducted by scanning buccally in centric occlusion intraorally to reach more precision of digital placement of the mandibular digital cast to the exact location to the maxillary digital cast. This technique allows avoiding issues related to materials used for the interocclusal record, trimming, positioning of the record, and post-operative distortion.
4) Avoiding of the possible complications related to a mechanical articulator such as (a) mounting and waiting for the plaster to set for both maxillary and mandibular cast which is considered time wasting, (b) cleaning the articulator cast from plaster, (c) the need to wait for the maxillary cast to dry and then bind it to the mandibular cast with a wax or low attaching compound.
5) Emulation of the fully adjustable articulator.

4.12. Disadvantages of CAD/CAM Technology

Although data obtaining systems are commonly used globally nowadays and huge advancement have been applied to these systems in recent years. However, there are still many barriers and insufficiencies to discuss about intraoral digital scanning (Su Ting-shu and Sun, 2015).

1) The need for a powder layer on the tooth surface in some systems, and the inhomogeneous powder thickness can slightly deform the tooth outline.
2) Scanning accuracy can be affected by displacement of the scanner during the process, which is another main issue.
3) The potential corruption of computers software by viruses and or harmful files, which might lead to lose work.
4) Expensive.
5) There is no need for employees so unemployment might increase and traditional hand skills will be lost.

4.13. CAD/CAM Systems

The leading intraoral digital impression systems that are available on the market today include STRAUMANN CARES IOS, CEREC, Lava C.O.S. system, and iTero. They are different from each other in key characteristics like working standard, light source, the need for powder coat spraying, operative process, and output file format.

4.13.1. CEREC system

Nowadays, the fourth generation of CEREC is the most widespread system, it is known as **CEREC AC Bluecam**. It records images with a visible blue light emerged from a LED blue diode which is the light source. The CEREC AC Bluecam is capable of recording one quadrant of the digital impression within 1 minute and the opposing in a few seconds.

The latest CEREC system, **CEREC AC Omnicam**, was presented in market in 2012. The Omnicam technique of recording is the type of continuous imaging, where sequential data obtaining creates a 3D model, while Bluecam records as a single image obtaining. Omnicam can be used for several indications, a single tooth, quadrant, or full arch, on the other hand, Bluecam is only used for a single tooth or quadrant. Omnicam most crucial features are the powder-free scanning and accurate 3D images with natural colors. The powder-free feature is particularly beneficial with scanning large areas (Birnbaum et al., 2009).

During the procedure of digital scanning, the clinician holds the scanner and direct the camera towards the required area. The tip of the camera should be only few millimeters far from tooth surface or just slightly touch the surface (Galhano GA et al., 2012). The clinician should slide the camera tip over the required teeth in a single direction gentle move to generate the consecutive imaging into a 3D model. This smooth scanning process can express a prominent profundity of field. Another feature is that the dentist can pause and resume the scan at any time.

To ensure that the captures images are accurate and stable, a new technology of shake detection has been developed and applied to this system to eliminate any potential incorrect imaging caused by trembling or shaking of the clinician's hand (Galhano GA et al., 2012).

When the scanning operation is completed, the scanned area and preparation can be seen on the screen to looked over from any desired angle. The virtual die is trimmed on the actual model then the finishing line is highlighted by the dentist straight on the die image. Then, a CAD system presents an optimal restoration design and allows the dentist to make adjustments if needed using many on-screen tools. When the desired design of restoration is completed, the dentist will set a block of ceramic or composite material with the suitable shade in the milling machine to start constructing the physical actual restoration.

This kind of intraoral scanner is used for single crowns, inlays, onlays, veneers and implant-supported FDPs. In cases of implant supported restorations, the prepared abutment can be directly scanned (Galhano GA et al., 2012), or a scan body placed on the implant can also be scanned. The scan body is a plastic coping used get the 3D registration of the implant location; the body has markers to ease the process (Patel N, 2010).

4.13.2. Straumann Cares IOS system

This type of systems (intra oral scanner) works depending on the novel 3D capture technology called multi- scan imaging, the extremely consolidated Straumann Cares intraoral scanner allows clinicians to make digital impressions readily and fast. This system also has one of the smallest handpieces presented in the market. It provides comfortable, convenient navigation due to the sound and gesture control feature.

A luminescent ring on the handpiece and voice signals refers to when scan data has been successfully recorded.

IOS has a gesture command wave to avert the usual touchscreen monitors. This technology provides allows touch-free control of the screen imagery while the clinician is wearing sterile gloves.

IOS scans a single unit in 20 seconds and a quadrant in two minutes.

In addition, the IOS system has an open files format that allows exporting files of 3D data as an STL file. The STL file can work along with other CAD/CAM systems.

4.13.3. Lava C.O.S. system

LavaTM C.O.S. (Lava Chairside Oral Scanner; 3M ESPE, Seefeld, Germany) is an intraoral digital impression unit found in 2006 and presented to market in 2008. Twenty 3D recordings can be captured per second, which represents over 10 000 data points in each scan (Syreket al., 2010). This allows the device to fabricate an accurate record out of 2 400 more datasets (or 24 million data points). The company claims that the high flow of data is due to many overlapping images that guarantee reaching high accuracy of scan quality (Syreket al., 2010). The Lava C.O.S. device has a very small scanner tip just 13.2 mm. The scanner sends out baulk visible blue light as light source and operate with a mobile host computer and a touch-screen display monitor (Galhano GA et al., 2012).

Same as in CEREC AC Bluecam, the Lava C.O.S. also needs a layer of powder to be applied on the tooth surfaces before scanning. After all important structures are recorded, a fast scan of the remaining part of the arch is needed as well. When the screen display a major missing or blurry parts in the scan, the clinician is asked to scan this particular part again and then software will adjust it automatically (Birnbaum et al., 2009). The dentist then scans the opposing arch in the same way. The final step is scanning the buccal side with the mouth in state of occlusion, and then the system will articulate the maxillary and mandibular teeth automatically to create a record of the bite (Birnbaum et al., 2008).

In many operations, the Lava C.O.S. also exports files in a strict formatted type, which can be designed and fabricated only by its compatible CAD software and CAM machine. Scanning of implant treatments is conducted by Biomet 3i (Palm Beach Gardens, FL). It is done with a healing cap (Encode; Biomet 3i) connected to the implant prior to taking an optical impression. After data obtaining, Biomet 3i will mill the abutment. The other option is to send the scan data to Dental Wings software (DWOS). The compatibility with some other software makes Lava C.O.S. a semi-open system (Galhano GA et al., 2012).

4.13.4. TRIOS system

In 2010, 3Shape (Copenhagen, Denmark) launched a new type of intraoral digital impression system, TRIOS, which was presented to market in 2011. a quick scanning speed of up to 3000 images per second reduces the influence of relative movement between scanner probe and teeth. By analyzing a large number of pictures obtained, the system ca create a final digital 3D model instantly to reflect the real configuration of teeth and gingival color. The TRIOS intraoral scanner is a powder-free device in the scanning process. operation of TRIOS is relatively simple, the dentist can hold the scanner at a range of distances to the tooth. Either closely over the tooth or 2 to 3 cm away will not affect the focus and the capturing of images.

The TRIOS system can provide service in a broad range o indications including crowns, FPDs, veneers, inlays, onlays, implants, and orthodontic cases. With the development of TRIOSR _ Color, it is expected that the patients with a removable partial denture or complete denture will be intraorally scanned directly in the future. The TRIOS system is an open system that can export 3D data as an STL file or a proprietary file. The STL file can work together with other CAD/CAM systems. The proprietary encrypted file can only be designed by 3Shape's specific CAD software and 3Shape Dental SystemTM. Additionally, TRIOS is a professional digita impression acquisition and CAD system, and does not include a CAM milling device (Logozzo et al., 2011).

4.14. The Future of Intraoral Scanning

In the coming years, new technologies will take place such as ultrasound impressions which is applied via ultrasonic waves, and they have the ability to gently go through the gingiva without any need for retraction cords and this method is not affected by sulcular fluid, blood or saliva. This improvement can assist to reach major and crucial move in this field, as careful cleaning and drying of the oral cavity or related structures will become needless. In addition to decreasing treatment duration and enhance patient leisure compared with optical impressions (Chuembou et al., 2015; Vollborn et al., 2014)

Moreover, milling blocks will be done using laser (Kazama-Koide et al., 2014) and/or directly inject printing (Ebert J et al., 2009) of zirconia and glass ceramics.

5. MATERIAL AND METHOD

5.1. Material

5.1.1. Patient selection and inclusion criteria

This project was approved by the Ethics Committee of Marmara University in Istanbul, Turkey (Application No:2017-71). All of the volunteers who understood the study and were willing to participate in signed the consent form and were recruited for the study.

5.1.1.1. Inclusion criteria

- Volunteers from faculty of dentistry of Marmara University.
- Aged at least eighteen years.
- Good oral hygiene.
- No temporomandibular joint disease.
- Complete maxillary and mandibular dental arch except the missing third molar.
- Intact hard and soft tissues.

5.1.1.2. Exclusion criteria

- With soft tissue lesions and postoperative scars on the palate.
- With oral implants.
- Advanced periodontitis affecting gingival recession.
- Obvious teeth mobility (mobility degree higher than 1).

The study includes ten volunteers, each volunteer received three digital impressions for both upper and lower jaw (three impression for the upper and three for the lower jaw) for each intraoral scanning system, and then the participants received one conventional impression for each jaw to serve as reference to evaluate the trueness.

5.1.2. Overview of the products and instruments used in the study

- CEREC Omnicam (OC; Sirona Dental Systems, Sirona, Bensheim, Germany)
- Straumann CARES IOS (Intra oral Scanner, Basel, Switzerland)
- Dentaco Scan Liquid titanium dioxide powder (Essen - Germany)

- Zetaplus poly-vinyl siloxane (Zhermack, Italy)
- Impresept disinfectant (3M ESPE, Seefeld, Germany)
- Vel-Mix™ Die Stone scannable Type IV dental stone (California, USA)
- 3Shape D700 laboratory scanner (Copenhagen, Denmark)
- Geomagic Control inspection software (Geomagic**,** Morrisville, USA)



Figure 5.1. Intraoral pictures

5.2. Method

5.2.1. Digital impressions

Tow intraoral scanning systems were evaluated in the study: CEREC Omnicam (OC; Sirona Dental Systems, Sirona, Bensheim, Germany); Straumann CARES IOS (Intra oral Scanner, Basel, Switzerland), and one quadrant was scanned from each jaw.

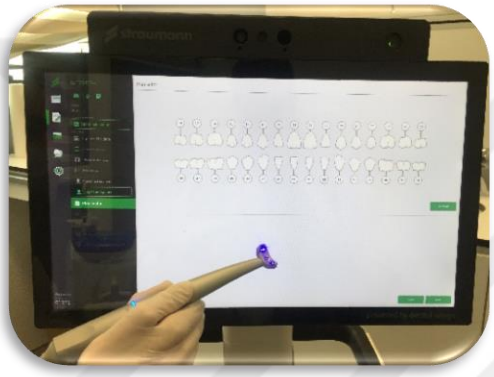


Figure 5.2. CARES scanner



Figure 5.3. CEREC scanner

The scan process was conducted following the manufacturer's guidelines, before which saliva was removed by cotton rolls and air syringe, and buccal or labial mucosa were pulled by cheek and lip retractor to avoid the negative effects of intraoral conditions as much as possible. Scanning is started with the second molar in the quadrant and ended at the central incisor of same quadrant. Each tooth was scanned from the occlusal , buccal and lingual surfaces. The camera of the scanner was aimed towards the scanned area. The camera tip was 5-10 millimeters away from the tooth. The camera head was slid over the teeth in a single direction gently to generate the successive data into a 3D model. This process was then repeated two times, so every volunteer had three digital impressions for each jaw for each system. All scans were performed by a well-trained dentist.

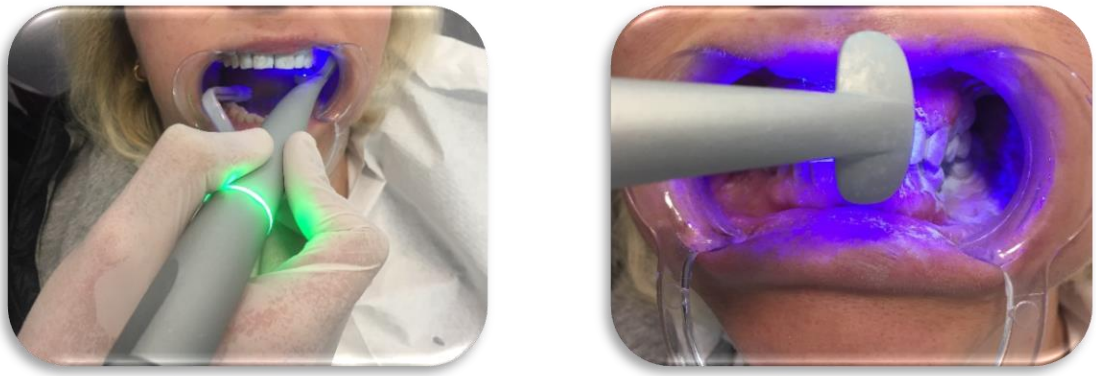


Figure 5.4. Scanning with CARES

As the CEREC system is a closed system exporting the digital impression data as a proprietary format file that works only on Sirona's supporting CAM devices, all the digital casts obtained with CEREC scanners were processed using CEREC SW 4.4.4 software to extract stereolithography (STL) files. An STL file format was compatible with and able to be imported into most 3D model processing softwares.



Figure 5.5. Scanning with CEREC

Additionally, CARES scanner works in camera image impression and requires a powder coating on the teeth surfaces. For this reason, the teeth in the quadrant were coated with a thin layer of titanium dioxide powder (dentaco scan liquid, Essen - Germany) before scanning with CARES.



Figure 5.6. Coating the teeth with titanium dioxide powder



Figure 5.7. Model made by CAREC

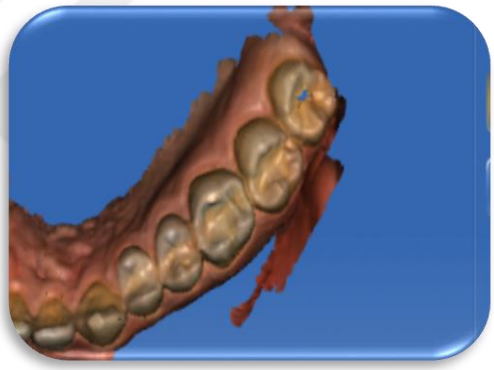


Figure 5.8. Model made by CEREC

5.2.2. Conventional impressions

Volunteer's conventional impression was obtained right after the completion of intraoral digital scanning. Standard perforated metal stock trays were used to generate the conventional impressions. The optimal tray was selected by testing a stock tray in the oral cavity while ensuring adequate space for the impression material. The conventional impressions were made using a poly-vinyl siloxane (PVS) material (Zetaplus, Zhermack, Italy) in one-step.

All impressions were disinfected for 10 minutes (Impresept; 3M ESPE, Seefeld, Germany) and then poured with scannable Type IV dental stone (Vel-Mix™ Die Stone,

California, USA). The impression trays were removed from the stone cast after 40 minutes, and the stone casts were stored at room temperature and humidity.



Figure 5.9. PVS impressions

Each cast was digitized once by a laboratory scanner (3Shape D700 scanner, Copenhagen, Denmark) after storage of at least 96 hours until the expansion of gypsum was complete to obtain the STL file format and considered as gold standard models.



Figure 5.10. 3Shape scanning device used to scan models



Figure 5.11. Digitizing the models and convert them to STL format

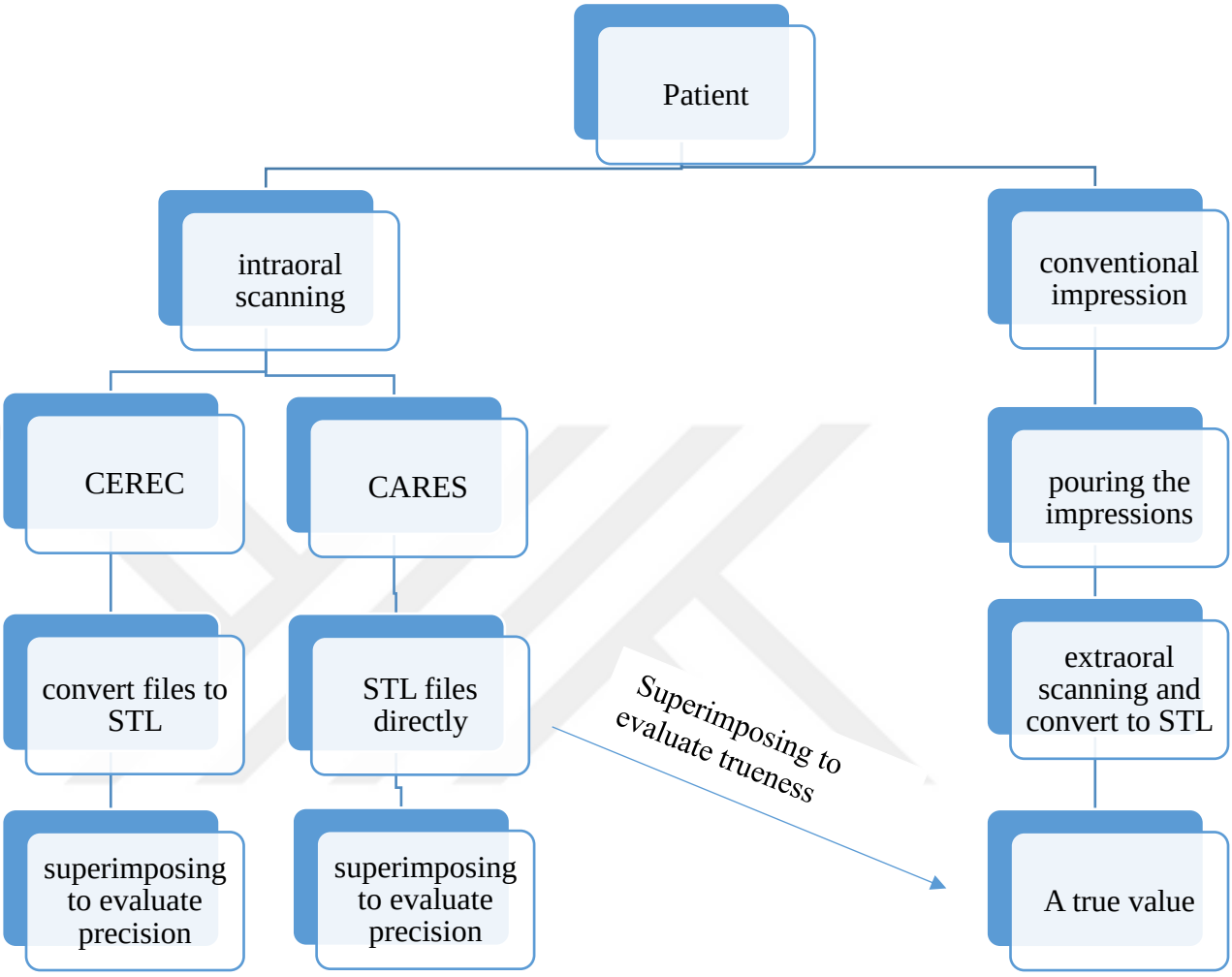


Figure 5.12. Diagram of study method

All STL datasets from intraoral scanner and gypsum casts were imported into the inspection software (Geomagic Control; Geomagic**,** Morrisville, USA). The STL data from each test group were pre-superimposed using CAD software (Geomagic Control; Geomagic**,** Morrisville, USA) according to a best-fit algorithm in order to align the orientations of the coordinate systems. To ensure a precise superimposition, the datasets were trimmed to field of interest (the dental arch, including the tooth surface and about 1 mm of attached gingiva). Therefore, all irrelevant areas were eliminated manually to ensure

precise superimposition and equal boundaries of all datasets. The trimmed models were again saved in STL file format and imported into Geomagic Control again for overall 3D compare.

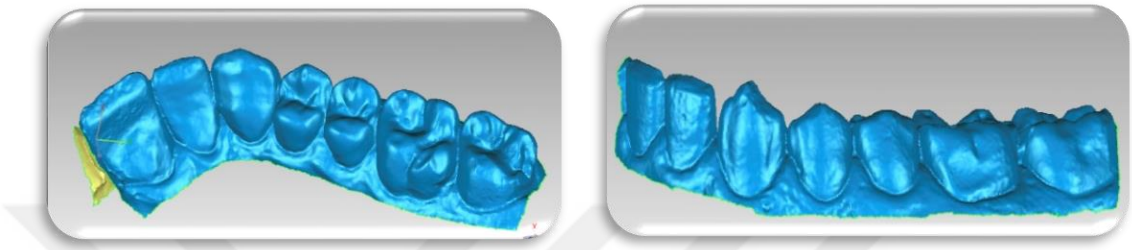


Figure 5.13. Trimmed models to ensure precise superimposition

For the 3D analysis, the digital of the control group and the experimental group were superimposed by using the best-fit tool, which the test model would be aligned to the reference model automatically in three dimensions. Color maps to show the differences between two aligned models and deviation information, such as average positive deviation, average negative deviation and standard deviation, were set to 20 color segments. The maximum and minimum critical values were set to ±50 μm. With these settings, 3D analysis results were derived, and color maps were derived as qualitative results.

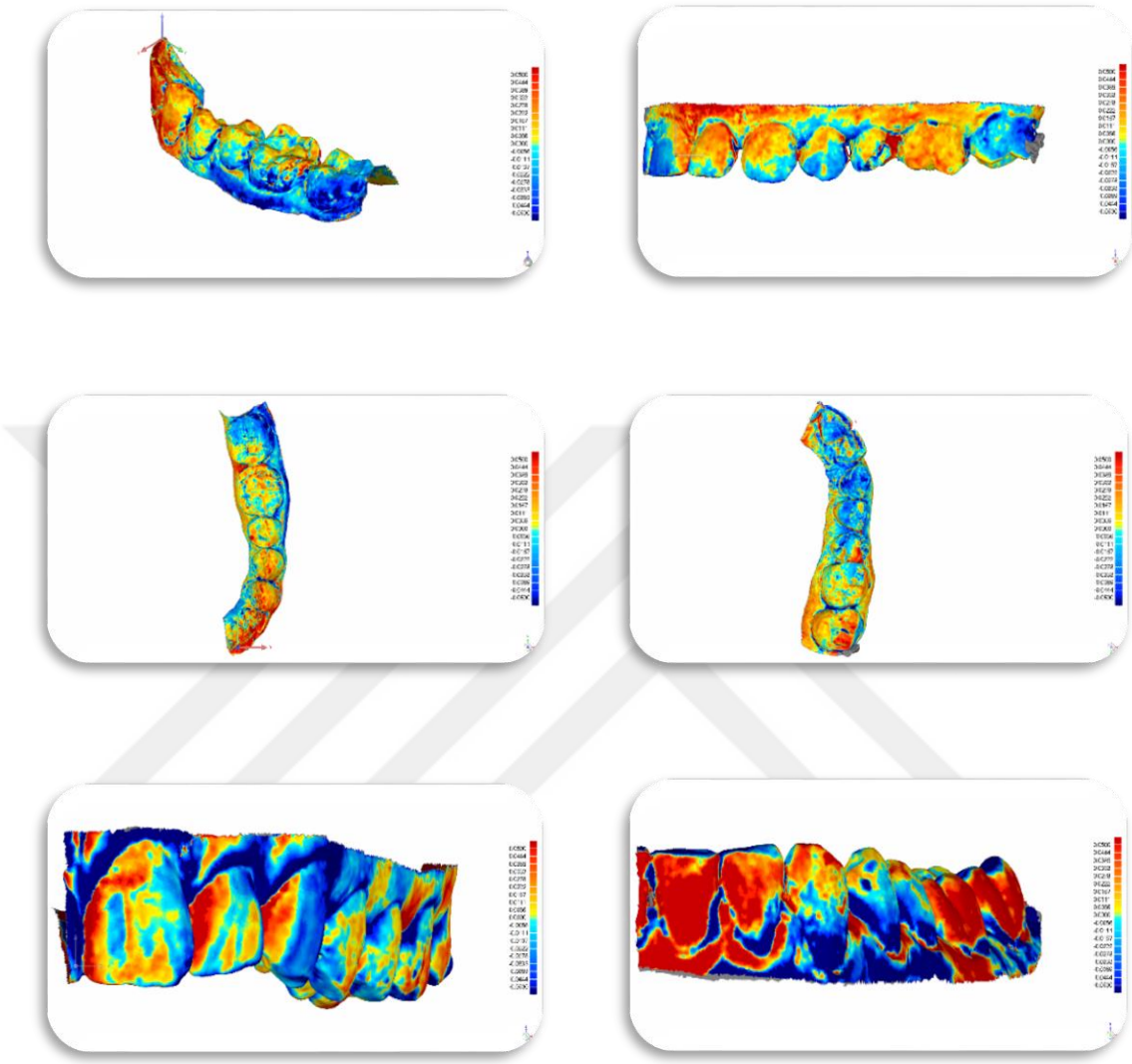


Figure 5.14. 3D analysis and color maps

5.2.3. Accuracy analysis

Trueness is defined as the comparison between digital impression (from each system) served as test model and a conventional impression served as reference model (true value) of the same volunteer. Precision is defined as the comparison between repeated digital scanning models obtained from one volunteer from the same scanner. Following the 3D compare of every pairs, deviation information expressed as mean absolute deviation (average positive deviation + average negative deviation/ 2) accounting for trueness and

standard deviation accounting for precision. The mean deviations of each volunteer were calculated.

5.2.4. Statistical analysis:

In this study statistical analysis was performed with SPSS statistic software (version 21.0, SPSS Inc., Chicago, Illinois, United States). For each group classification, the mean value, the standard deviation (SD), the minimum and the maximum was calculated. For analyzing two- and three dimensional deviations, one-way ANOVA was performed. LSD (least significant difference) test for post hoc comparison was conducted. The statistical significance was set at ($p < 0.05$).

6. RESULTS

6.1. Dertermine Trueness

After the models were imported to Geomagic Control software the superimpositions were done, the tables are shown in the tables below.

6.1.1. Distribution tables

Table 6.1. Superimposition results of CEREC AC Omnicam and conventional empression for upper jaw (μm)

Scanner type	jaw	average positive deviation	average negative deviation	mean
CEREC AC Omnicam	upper jaw	135,5	128,8	132,15
CEREC AC Omnicam	upper jaw	167	236,6	201,8
CEREC AC Omnicam	upper jaw	83,6	94,5	89,05
CEREC AC Omnicam	upper jaw	124,1	113	118,55
CEREC AC Omnicam	upper jaw	74,2	81,1	77,65
CEREC AC Omnicam	upper jaw	57,5	103,7	80,6
CEREC AC Omnicam	upper jaw	67,6	61,4	64,5
CEREC AC Omnicam	upper jaw	114,3	83,2	98,75
CEREC AC Omnicam	upper jaw	73,7	84,2	78,95
CEREC AC Omnicam	upper jaw	55,8	57,8	56,8

Table 6.2. Superimposition results of CARES and conventional empression for upper jaw (μm)

Scanner type	jaw	average positive deviation	average negative deviation	mean
CARES	upper jaw	100,3	120,6	110,45
CARES	upper jaw	145	118,4	131,7
CARES	upper jaw	100	102,5	101,25
CARES	upper jaw	124,9	109,4	117,15
CARES	upper jaw	98,9	84,9	91,9
CARES	upper jaw	112,2	87,8	100
CARES	upper jaw	85,5	85,3	85,4
CARES	upper jaw	162,6	150,3	156,45
CARES	upper jaw	99,2	94,1	96,65
CARES	upper jaw	60,7	68	64,35

Table 6.3. Superimposition results of CEREC AC Omnicam and conventional empression for lower jaw (μm)

Scanner type	jaw	average positive deviation	average negative deviation	mean
CEREC AC Omnicam	Lower jaw	86,2	63,3	74,75
CEREC AC Omnicam	Lower jaw	131,7	144,6	138,15
CEREC AC Omnicam	Lower jaw	57,9	67,8	62,85
CEREC AC Omnicam	Lower jaw	118,6	85,2	101,9
CEREC AC Omnicam	Lower jaw	76	76,5	76,25
CEREC AC Omnicam	Lower jaw	95,2	131,6	113,4
CEREC AC Omnicam	Lower jaw	49,1	56,1	52,6
CEREC AC Omnicam	Lower jaw	81	67,1	74,05
CEREC AC Omnicam	Lower jaw	65,3	76,7	71
CEREC AC Omnicam	Lower jaw	67,3	54,8	61,05

Table 6.4. Superimposition results of CARES and conventional empression for lower jaw (μm)

Scanner type	jaw	average positive deviation	average negative deviation	mean
CARES	Lower jaw	129,7	105,8	117,75
CARES	Lower jaw	148,3	187	167,65
CARES	Lower jaw	124,6	108,3	116,45
CARES	Lower jaw	158,9	102,6	130,75
CARES	Lower jaw	89,3	77	83,15
CARES	Lower jaw	174,8	161,7	168,25
CARES	Lower jaw	73,4	71,8	72,6
CARES	Lower jaw	93,1	74,9	84
CARES	Lower jaw	90,5	75,7	83,1
CARES	Lower jaw	74,9	68,9	71,9

6.1.2. Descriptive statistics

Table 6.5. Descriptive statistics of trueness groups

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
average positive deviation	CEREC AC Omnicam- upper jaw	10	95,3300	37,64218	11,90350	68,4024	122,2576	55,80	167,00
	CEREC AC Omnicam- lower jaw	10	82,8300	26,22518	8,29313	64,0696	101,5904	49,10	131,70
	CARES- upper jaw	10	108,9300	29,19635	9,23270	88,0442	129,8158	60,70	162,60
	CARES - lower jaw	10	115,7500	36,50523	11,54397	89,6357	141,8643	73,40	174,80
	Total	40	100,7100	33,98033	5,37276	89,8426	111,5774	49,10	174,80
average negative deviation	CEREC AC Omnicam- upper jaw	10	104,4300	51,27874	16,21576	67,7474	141,1126	57,80	236,60
	CEREC AC Omnicam- lower jaw	10	82,3700	30,96615	9,79236	60,2182	104,5218	54,80	144,60
	CARES- upper jaw	10	102,1300	23,55608	7,44909	85,2790	118,9810	68,00	150,30
	CARES - lower jaw	10	103,3700	40,66607	12,85974	74,2792	132,4608	68,90	187,00
	Total	40	98,0750	37,71975	5,96402	86,0116	110,1384	54,80	236,60
mean absolute deviation	CEREC AC Omnicam- upper jaw	10	99,8800	42,56728	13,46096	69,4292	130,3308	56,80	201,80
	CEREC AC Omnicam- lower jaw	10	82,6000	26,81419	8,47939	63,4183	101,7817	52,60	138,15
	CARES- upper jaw	10	105,5300	25,49834	8,06328	87,2896	123,7704	64,35	156,45
	CARES - lower jaw	10	109,5600	36,84469	11,65131	83,2029	135,9171	71,90	168,25
	Total	40	99,3925	33,99878	5,37568	88,5192	110,2658	52,60	201,80

Table 6.5 gives the mean values and their standard deviation, as well as the minimum, median, maximum and 95 % confidence interval for each parameter after superimposition. The measurement results (mean ±standard deviation) for trueness were : 99,88±42,56 μm for CEREC Omnicam in upper jaw, 82,6±26,81 μm for Omnicam in lower jaw, 105,53±25,49 μm for CARES in upper jaw, and 109,56±36,84 μm for CARES in lower jaw.

The one-way analysis of variance (ANOVA) test was performed after the descriptive analysis to determine whether there are any statistically significant differences among study groups. ANOVA test result is shown in table 6.6.

Table 6.6. ANOVA test result to determine trueness

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
mean absolute deviation	Between Groups	4232,727	3	1410,909	1,243	0,308
	Within Groups	40848,031	36	1134,668		
	Total	45080,758	39			

According to ANOVA, differences in trueness between CEREC Omnicam and CARES in both upper and lower jaw did not differ significantly (P>0.05).

6.2. Dertermine Precision

After the models wrer imported to Geomagic Control software the superimpositions were done, the tables are shown in the tables below.

6.2.1. Distribution tables

Table 6.7. Superimposition results of CEREC AC Omnicam empressions for upper jaw (μm)

Scanner type	jaw	Superimposition 1-2 (SD)	Superimposition 1-3 (SD)	mean
CEREC AC Omnicam	upper jaw	99	84,4	91,7
CEREC AC Omnicam	upper jaw	72,1	66,4	69,25
CEREC AC Omnicam	upper jaw	99,1	63,7	81,4
CEREC AC Omnicam	upper jaw	60,2	73,3	66,75
CEREC AC Omnicam	upper jaw	45,2	46,4	45,8
CEREC AC Omnicam	upper jaw	85	74,3	79,65
CEREC AC Omnicam	upper jaw	44,9	51	47,95
CEREC AC Omnicam	upper jaw	55,2	52,4	53,8
CEREC AC Omnicam	upper jaw	110,9	44,3	77,6
CEREC AC Omnicam	upper jaw	51,1	45	48,05

Table 6.8. Superimposition results of CARES empressions for upper jaw (μm)

Scanner type	jaw	Superimposition 1-2 (SD)	Superimposition 1-3 (SD)	mean
CARES	upper jaw	218	241,8	229,9
CARES	upper jaw	228,5	214,2	221,35
CARES	upper jaw	147,4	152	149,7
CARES	upper jaw	110,9	113,4	112,15
CARES	upper jaw	141,4	92,4	116,9
CARES	upper jaw	151,7	123,7	137,7
CARES	upper jaw	87,4	136,1	111,75
CARES	upper jaw	187,8	0,9	94,35
CARES	upper jaw	176,1	16,3	96,2
CARES	upper jaw	71	114,1	92,55

Table 6.9. Superimposition results of CEREC AC Omnicam empressions for lower jaw (μm)

Scanner type	jaw	Superimposition 1-2 (SD)	Superimposition 1-3 (SD)	mean
CEREC AC Omnicam	Lower jaw	158,7	99,2	128,95
CEREC AC Omnicam	Lower jaw	87,1	66,5	76,8
CEREC AC Omnicam	Lower jaw	171,6	89,6	130,6
CEREC AC Omnicam	Lower jaw	57,9	54,9	56,4
CEREC AC Omnicam	Lower jaw	67,1	45,9	56,5
CEREC AC Omnicam	Lower jaw	94,9	51,7	73,3
CEREC AC Omnicam	Lower jaw	50,3	47,5	48,9
CEREC AC Omnicam	Lower jaw	148,4	52,4	100,4
CEREC AC Omnicam	Lower jaw	111,4	32,4	71,9
CEREC AC Omnicam	Lower jaw	114,5	66,1	90,3

Table 6.10. Superimposition results of CARES empressions for lower jaw (μm)

Scanner type	jaw	Superimposition 1-2 (SD)	superimposition 1-3 (SD)	mean
CARES	Lower jaw	184	165,2	174,6
CARES	Lower jaw	110,7	78,4	94,55
CARES	Lower jaw	160,1	98,2	129,15
CARES	Lower jaw	104,3	213	158,65
CARES	Lower jaw	87,5	84	85,75
CARES	Lower jaw	272,1	97,6	184,85
CARES	Lower jaw	98,6	96,8	97,7
CARES	Lower jaw	92,1	90,2	91,15
CARES	Lower jaw	146,6	147,5	147,05
CARES	Lower jaw	86,8	116,2	101,5

6.2.2. Descriptive statistics

Table 6.11. Descriptive statistics of precision groups

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
superimposition 1-2 (SD)	CEREC AC Omnicam- upper jaw	10	72,2700	24,62122	7,78591	54,6570	89,8830	44,90	110,90
	CEREC AC Omnicam- lower jaw	10	106,1900	42,67342	13,49452	75,6633	136,7167	50,30	171,60
	CARES- upper jaw	10	152,0200	52,31069	16,54209	114,5992	189,4408	71,00	228,50
	CARES - lower jaw	10	134,2800	58,91108	18,62932	92,1376	176,4224	86,80	272,10
	Total	40	116,1900	54,09094	8,55253	98,8909	133,4891	44,90	272,10
superimposition 1-3 (SD)	CEREC AC Omnicam- upper jaw	10	60,1200	14,24569	4,50488	49,9293	70,3107	44,30	84,40
	CEREC AC Omnicam- lower jaw	10	60,6200	20,43389	6,46176	460025	75,2375	32,40	99,20
	CARES- upper jaw	10	120,4900	75,11621	23,75383	66,7551	174,2249	0,90	241,80
	CARES - lower jaw	10	118,7100	43,30246	13,69344	87,7333	149,6867	78,40	213,00
	Total	40	89,9850	52,70657	8,33364	73,1286	106,8414	0,90	241,80
mean SD	CEREC AC Omnicam- upper jaw	10	66,1950	16,44574	5,20060	54,4304	77,9596	45,80	91,70
	CEREC AC Omnicam- lower jaw	10	83,4050	28,98262	9,16511	62,6721	104,1379	48,90	130,60
	CARES- upper jaw	10	136,2550	50,57461	15,99310	100,0761	172,4339	92,55	229,90
	CARES - lower jaw	10	126,4950	37,36711	11,81652	99,7642	153,2258	85,75	184,85
	Total	40	103,0875	45,16223	7,14077	88,6439	117,5311	45,80	229,90

Table 6.11 gives the mean values and their standard deviation, as well as the minimum, median, maximum and 95 % confidence interval for each parameter after superimposition. The measurement results (mean ±standard deviation) for precision were : 66,19±16,44 μm for CEREC Omnicam in upper jaw, 83,4±28,98 μm for Omnicam in lower jaw, 136,25±50,57 μm for CARES in upper jaw, and 126,49±37,36 μm for CARES in lower jaw.

The one-way analysis of variance (ANOVA) test was performed after the descriptive analysis to determine whether there are any statistically significant differences among study groups. ANOVA test result is shown in table6.12.

Table 6.12. ANOVA test results to determine precision

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
mean SD	Between Groups	33964,515	3	11321,505	8,942	0,000
	Within Groups	45580,924	36	1266,137		
	Total	79545,439	39			

According to ANOVA, differences in precision between CEREC Omnicam and CARES differ significantly ($P<0.05$).

To determine differences among the study groups LSD (least significant difference) test for post hoc comparison was performed.

6.2.3. Post hoc tests LSD

To detect the different group least significant difference LSD test was done, LSD results are detailed in table 6.13.

6.2.3.1. Multiple comparisons

Table 6.13. LSD test results on study groups

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
mean SD	CEREC AC Omnicam-upper jaw	CEREC AC Omnicam-lower jaw	-17,21000	15,91312	0,287	-49,4833	15,0633
		CARES-upper jaw	-70,06000*	15,91312	0,000	-102,3333	-37,7867
		CARES-lower jaw	-60,30000*	15,91312	0,001	-92,5733	-28,0267
	CEREC AC Omnicam-lower jaw	CEREC AC Omnicam-upper jaw	17,21000	15,91312	0,287	-15,0633	49,4833
		CARES-upper jaw	-52,85000*	15,91312	0,002	-85,1233	-20,5767
		CARES-lower jaw	-43,09000*	15,91312	0,010	-75,3633	-10,8167
	CARES-upper jaw	CEREC AC Omnicam-upper jaw	70,06000*	15,91312	0,000	37,7867	102,3333
		CEREC AC Omnicam-lower jaw	52,85000*	15,91312	0,002	20,5767	85,1233
		CARES-lower jaw	9,76000	15,91312	0,544	-22,5133	42,0333
	CARES-lower jaw	CEREC AC Omnicam-upper jaw	60,30000*	15,91312	0,001	28,0267	92,5733
		CEREC AC Omnicam-lower jaw	43,09000*	15,91312	0,010	10,8167	75,3633
		CARES-upper jaw	-9,76000	15,91312	0,544	-42,0333	22,5133
*. The mean difference is significant at the 0,05 level.							

The LSD test results shows the significantly different groups among the study groups according to statistical significance ($p < 0.05$), and accordingly it indicates that Omnicam groups (66,19±16,44 μm in upper jaw, 83,4±28,98 μm in lower jaw) was significantly more precise than CARES groups (136,25±50,57 μm in upper jaw, and 126,49±37,36 μm in lower jaw). There were no significant differences between upper and lower jaws in same scanner.

7. DISCUSSION

The null hypothesis was (1) because of requiring a layer of powder, the inhomogeneous powder thickness may slightly affect the accuracy comparing with powder free system. (2) Significant differences between upper and lower jaws impressions can be found.

In the light of the results, the null hypothesis was partially rejected, (1) No significant differences were found between two scanning devices concerning the trueness, while there were significant differences ($p < 0.05$) in the precision, CEREC OC showed lower deviation and consequently higher precision than CARES. (2) No significant differences ($p > 0.05$) were found between upper and lower jaw among the study groups.

Because of the increase in the use of CAD/CAM in many aspects of dentistry such as restorative, surgery, orthodontics, digital impression has to present a high level of accuracy. To eliminate the conventional impression and stone model, digital impressions should meet at least the same level of the accuracy as conventional techniques. The aim of this in vivo study was to compare the accuracy of the digital systems in quadrant impressions.

It is a common method to express the accuracy as a trueness and precision. As applied in prior studies, to analyze the trueness: superimposition of the test data with the reference data is done, and superimposition of the test data under each other to analyze the precision (Güth et al., 2016).

In the light of this aim, authors did many studies to assess the accuracy of impression techniques, (Güth et al., 2016) evaluated both trueness and precision as components of the accuracy of digital impression and the indirect digitalization. In the other published studies, the authors focused on the precision of different dental impression methods, (Ender et al., 2016) compared in –in vivo- study the precision of conventional impression with vinylsiloxanether and seven digital systems (Lava True Definition Scanner, Lava COS

,iTero, 3Shape Trios, 3Shape Trios Color, CEREC Bluecam, and CEREC Omnicam) to obtain quadrant dental impressions. In this in-vivo study, both precision and trueness were calculated as components of the accuracy.

Some studies compared the accuracy of direct and indirect impression methods while others compared the direct digital systems among each other, in (Vecsei et al., 2016) study, they compared direct digital impression made by three systems (iTero, Cerec, Trios) with indirect process based on Polyvinyl-siloxane impression. (Renne et al., 2017) evaluated the accuracy of 7 intraoral scanners (CEREC Omnicam, CEREC Bluecam, Planmeca Planscan, iTero, Carestream 3500, 3Shape TRIOS, and 3Shape D800 model scanner). Current study was made to compare the accuracy between two direct digital systems (CEREC Omnicam, STRAUMANN CARES IOS).

Although several studies have been made to evaluate the trueness and precision of digital and conventional impression, the design of these studies was made in different ways. Different methods and materials were used in the light of same aim.

For the scanned field, some researchers create models with prepared teeth, (Vecsei et al., 2016) used PMMA (polymethyl methacrylate) model with four prepared teeth (first premolars, left central incisor and left second molar). (Güth et al., 2016) used a titanium model with prepared premolar and molar teeth. (Ender et al., 2016; Güth et al., 2016; Flügge et al., 2013) scanned full arch with no prepared teeth in their in vivo studies. (Renne et al., 2017) made both posterior sextant and full arch scans in their in vitro study. (Ender et al., 2016) selected upper and lower jaw randomly by coin toss in their study of the precision of complete arch impression. In the present in vivo study, one-quadrant impressions for both upper and lower jaws were taken from each patient to examine if there is a difference in the accuracy between upper and lower jaw. The full arch impression was not used because CARES Company (Straumann) has already reported that it has no high accuracy in full arch intra oral scanning.

For the conventional impressions material selection, the material used must achieve a high accuracy impression to exclude the negative effects of the distortion of the impression material on the accuracy, (Ender et al., 2016) used vinylsiloxanether

impression material. (Flügge et al 2013) took the impression with polyether in their study. most of the studies such as (Vecsei et al., 2016) Vecsei et al., 2016) used PVS (polyvinyl siloxanes) since it is one of the frequently used impression materials in dentistry; it is proved to insure accurate impression of the oral cavity. For the same reason, PVS (polyvinyl siloxanes) material was used in the present study to obtain the conventional impression to serve as our reference model.

Discussing the superimposition software and process, authors used (Geomagic Control; Geomagic**,** Morrisville, USA) software to achieve the superimposition process after converting all datasets to STL format, some studies estimate the linear distance measurements like (Vecsei et al., 2016) study, the distances between prepared teeth were measured also by Geomagic software, and most of the others used the whole deviation of the STL models (Güth et al., 2016; Renne et al.,2017; Gan et al., 2016). In accordance, Geomagic software was used and whole deviation was measured in this study.

To evaluate to precision, comparison between repeated scanning models obtained from one patient from the same scanner is done, In order to evaluate the trueness, it has to be a reference dataset to compare the STL files gathered from different impression methods to it. In (Güth et al., 2016; Renne et al.,2017; Vecsei et al., 2016) in vitro studies, after creating the study model they digitized it by an industrial 3D scanner (Capture 3D Company) and used it as master (reference) model, this scanner has been demonstrated to have a high accuracy. (Gan et al., 2016) create the reference model in vivo depends on conventional impression after pouring the impression and extra-oral scanning the casts. Similar to (Gan et al., 2016) in this study, the dataset provided from the conventional impressions were served as master (reference) model. The exact evaluating of the trueness cannot be achieved in vivo yet because of the missing of the reference structures (true value). But, in vitro trueness results can be integrated with in vivo studies of the reproducibility (precision), so it can give a good image about the performance of the intra oral scanner.

Another method to evaluate the accuracy in the studies is to assess the marginal adaptation of a restoration made depending on digital and conventional impression

techniques. (Abdel-Azim et al 2015; Shembesh et al., 2016) measured the marginal gaps of a crown and bridge made from conventional impression and different intra oral scanning systems.

Although the direct comparison with other published results is difficult due to the wide variations in study design, the results of this study are compatible with values presented in the literature for accuracy (precision and trueness) of digital scanning systems. In (Renne et al., 2017) study, the mean value of trueness in sextant for CEREC OC was 56,2 μm and 107,6 μm for complete arch, while the mean value of precision was 89,8 μm in sextant and 133,4 μm in complete arch. (Ender et al., 2016) study showed mean precision at 48,6 μm for CEREC OC in their study.in (Güth et al., 2016) study on two prepared titanium teeth, the mean value of the trueness was 31 μm. According to (Ender et al., 2016) study on quadrant, the value of the precision was 37,4 μm. The results of current study are in accordance with the published studies, the mean values of CEREC OC trueness were 82,6 in lower jaw and 99,8 in upper jaw, while the precision values were 66,19 μm for upper jaw and 83,4 for the lower.

In the systems which need a layer of powder; in (Ender et al., 2016) study on complete arch impressions, the precision values was 56,4 μm for CEREC Bluecam, 59,7 μm for True Definition Scanner (T-Def; 3M ESPE), and 82,8 μm for Lava COS (LAV; 3M ESPE). In (Renne et al., 2017) study, the mean value of trueness in sextant for CEREC Bluecam was 57,5 μm and 155,6 μm for complete arch, while the mean value of precision was 89,6 μm in sextant and 194,2 μm in complete arch. The results of current study for CARES as a powder needed scanner were similar to the published study or a little bit higher, where the deviation of the trueness was 105,53 μm in upper jaw and 109,56 μm in lower jaw, while the precision values were 136,25 μm for upper jaw and 126,49 μm for the lower. This shows that the CARES has lower accuracy than the other scanners previously mentioned.

8. Conclusion

Within the limitation of this in vivo study, both of the intraoral scanning systems were capable to give quadrant impression with clinically satisfying accuracy, there were differences between the two systems in precision but although they were statistically significant, they were in a range that allows producing a successful restoration with the digital workflow.

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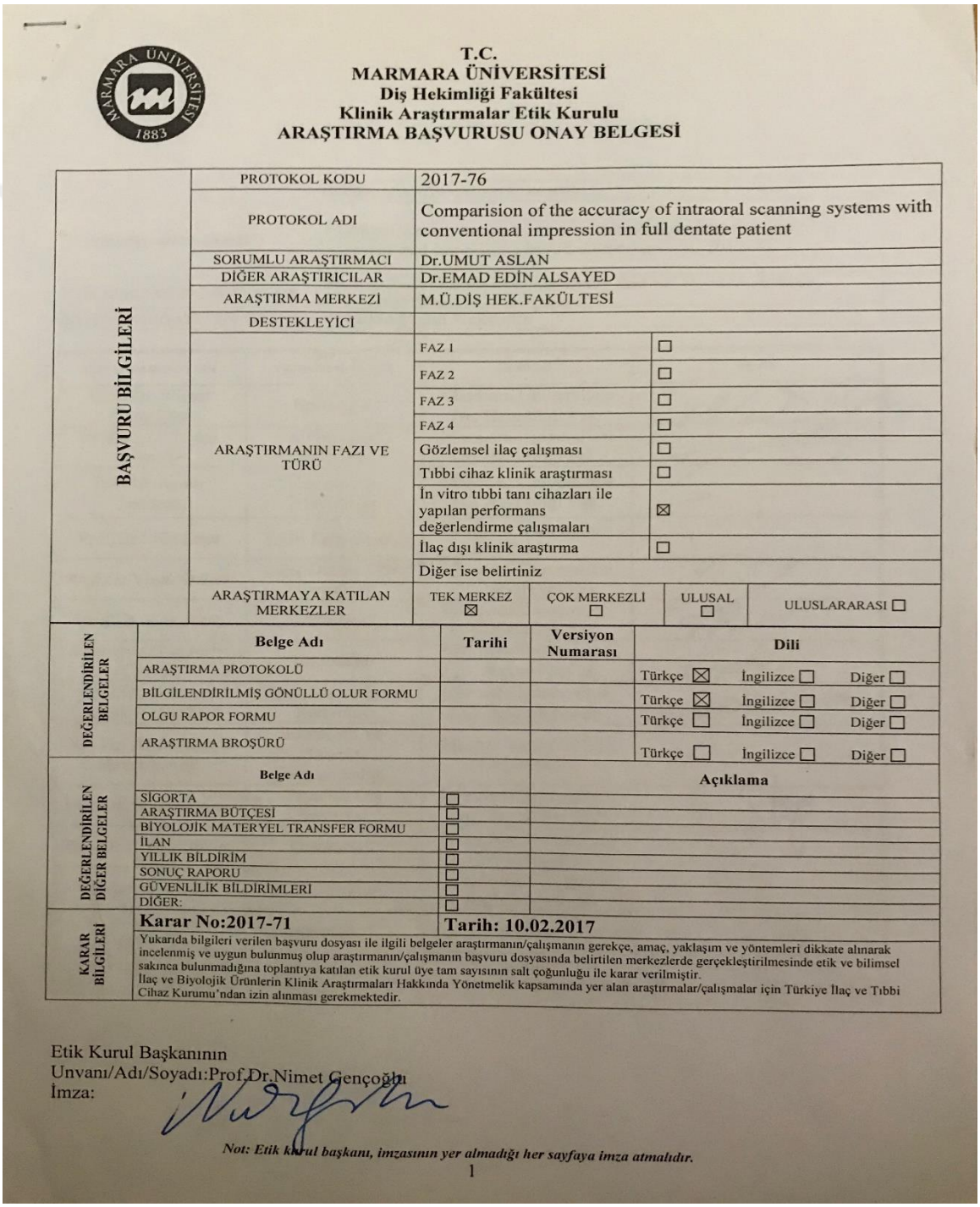
10. Enclosures

10.1. Ethical Committee Approval



T.C.
MARMARA ÜNİVERSİTESİ
Diş Hekimliği Fakültesi
Klinik Araştırmalar Etik Kurulu
ARAŞTIRMA BAŞVURUSU ONAY BELGESİ

BAŞVURU BİLGİLERİ					
	PROTOKOL KODU	2017-76			
	PROTOKOL ADI	Comparision of the accuracy of intraoral scanning systems with conventional impression in full dentate patient			
	SORUMLU ARAŞTIRMACI	Dr.UMUT ASLAN			
	DİĞER ARAŞTIRICILAR	Dr.EMAD EDİN ALSAYED			
	ARAŞTIRMA MERKEZİ	M.Ü.DİŞ HEK.FAKÜLTESİ			
	DESTEKLEYİCİ				
	ARAŞTIRMANIN FAZI VE TÜRÜ	FAZ 1	☐		
		FAZ 2	☐		
		FAZ 3	☐		
		FAZ 4	☐		
		Gözlemsel ilaç çalışması	☐		
		Tıbbi cihaz klinik araştırması	☐		
		İn vitro tıbbi tanı cihazları ile yapılan performans değerlendirme çalışmaları	☒		
		İlaç dışı klinik araştırma	☐		
		Diğer ise belirtiniz			
	ARAŞTIRMAYA KATILAN MERKEZLER	TEK MERKEZ ☒	ÇOK MERKEZLİ ☐	ULUSAL ☐	ULUSLARARASI ☐

DEĞERLENDİRİLEN BELGELER	Belge Adı	Tarihi	Versiyon Numarası	Dili		
	ARAŞTIRMA PROTOKOLÜ			Türkçe ☒	İngilizce ☐	Diğer ☐
	BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU			Türkçe ☒	İngilizce ☐	Diğer ☐
	OLGU RAPOR FORMU			Türkçe ☐	İngilizce ☐	Diğer ☐
	ARAŞTIRMA BROŞÜRÜ			Türkçe ☐	İngilizce ☐	Diğer ☐

DEĞERLENDİRİLEN DİĞER BELGELER	Belge Adı		Açıklama
	SİGORTA	☐	
	ARAŞTIRMA BÜTÇESİ	☐	
	BİYOLOJİK MATERYEL TRANSFER FORMU	☐	
	İLAN	☐	
	YILLIK BİLDİRİM	☐	
	SONUÇ RAPORU	☐	
	GÜVENLİLİK BİLDİRİMLERİ	☐	
	DİĞER:	☐	

KARAR BİLGİLERİ		
	Karar No:2017-71	**Tarih: 10.02.2017**
	Yukarıda bilgileri verilen başvuru dosyası ile ilgili belgeler araştırmanın/çalışmanın gerekçe, amaç, yaklaşım ve yöntemleri dikkate alınarak incelenmiş ve uygun bulunmuş olup araştırmanın/çalışmanın başvuru dosyasında belirtilen merkezlerde gerçekleştirilmesinde etik ve bilimsel sakınca bulunmadığına toplantıya katılan etik kurul üye tam sayısının salt çoğunluğu ile karar verilmiştir. İlaç ve Biyolojik Ürünlerin Klinik Araştırmaları Hakkında Yönetmelik kapsamında yer alan araştırmalar/çalışmalar için Türkiye İlaç ve Tıbbi Cihaz Kurumu'ndan izin alınması gerekmektedir.	

Etik Kurul Başkanının
Unvanı/Adı/Soyadı:Prof.Dr.Nimet Gençoğlu
İmza:

Not: Etik kurul başkanı, imzasının yer almadığı her sayfaya imza atmalıdır.

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T.C.
MARMARA ÜNİVERSİTESİ
Diş Hekimliği Fakültesi
Klinik Araştırmalar Etik Kurulu
ARAŞTIRMA BAŞVURUSU ONAY BELGESİ

KLİNİK ARAŞTIRMALAR ETİK KURULU	
PROTOKOL ADI VE KODU	Comparision of the accuracy of intraoral scanning systems with conventional impression in full dentate patient, 2017-76
ETİK KURULUN ÇALIŞMA ESASI	İlaç ve Biyolojik Ürünlerin Klinik Araştırmaları Hakkında Yönetmelik, İyi Klinik Uygulamaları Kılavuzu
BAŞKANIN UNVANI / ADI / SOYADI:	**Prof.Dr.Nimet Gençoğlu**

UNVANI/ADI/SOYADI	UZMANLIK ALANI	KURUMU	İMZA
Prof. Dr. Nimet Gençoğlu	Endodonti	Marmara Üniversitesi Diş Hekimliği Fak.	
Prof.Dr.Ali Recai Menteş	Çocuk Diş Hekimliği	Marmara Üniversitesi Diş Hekimliği Fak.	
Prof.Dr.İlknur Tanboğa	Çocuk Diş Hekimliği	Marmara Üniversitesi Diş Hekimliği Fak.	
Prof.Dr.Filiz Onat	Tıbbi Farmakoloji	Marmara Üniversitesi Tıp Fakültesi	
Prof.Dr.Yaşar Özkan	Ağız Diş ve Çene Cerrahisi	Marmara Üniversitesi Diş Hekimliği Fak.	
Prof.Dr. Ahu Acar	Ortodonti	Marmara Üniversitesi Diş Hekimliği Fak.	
Prof.Dr.Zühre Hale Cimilli	Endodonti	Marmara Üniversitesi Diş Hekimliği Fak.	
Prof.Dr. Şebnem Erçalık Yalçınkaya	Ağız Diş ve Çene Radyoloji	Marmara Üniversitesi Diş Hekimliği Fak.	
Doç.Dr. Afife Binnaz Hazar Yoruç	Metalürji ve Malzeme Mühendisliği	İstanbul Yıldız Teknik Üniversitesi	
Doç.Dr. Buket Evren	Protetik Diş Tedavisi	Marmara Üniversitesi Diş Hekimliği Fak.	
Doç.Dr. Tolga Güven	Deontoloji	Marmara Üniversitesi Tıp Fakültesi	
Dr. Zerrin Kurşun	Halk Sağlığı	Çekmeköy Toplum Sağlığı Merkezi	
Avukat Burçak Çopuroğlu	Hukuk	Serbest	
Gürol Pekel	Sivil	Serbest	

Etik Kurul Başkanının
Unvanı/Adı/Soyadı:Prof.Dr.Nimet Gençoğlu
İmza:

Not: Etik kurul başkanı, imzasının yer almadığı her sayfaya imza atmalıdır.

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11. CURRICULUM VITAE

Name	Imadettin	**Surname**	ALSAYED
Place of Birth	Damascus	**Date of Birth**	31.07.1989
Nationality	Syrian - Turkish	**Tel**	00905514425246
E-mail	dr.emaaad15@hotmail.com		

Educational Level

	Name of the Institution where he/she was graduated	**Graduation year**
Masters	Marmara University Faculty of Dentistry Department of Prosthodontics	
Undergraduate	Damascus University Faculty of Dentistry	
High school	Al-Andalus School	

Job Experience

	Duty	**Institution**	**Duration (Year - Year)**

Foreign Languages	**Reading comprehension**	**Speaking***	**Writing***
English	Good	Good	Good
Turkish	Very good	Very good	Very good
Arabic	Mother language	Mother language	Mother language

Foreign Language Examination Grade#								
YDS	ÜDS	IELTS	TOEFL IBT	TOEFL PBT	TOEFL CBT	FCE	CAE	CPE
			66					

	Math	**Equally weighted**	**Non-math**
ALES Grade			
(Other) Grade			

Computer Knowledge

Program	**Use proficiency**
Microsoft office	Good

*****Evaluate as very good, good, moderate, poor.

ENCLOSURE: Other scientific activities (publication, congress proceedings etc.)