T.C.

YEDITEPE UNIVERSITY

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THREE-DIMENSIONAL ACCURACY COMPARISON OF DIGITAL AND CONVENTIONAL IMPRESSION METHODS IN FULL-ARCH IMPLANT IMPRESSION

DOCTOR OF PHILOSOPHY THESIS

ILGIN ÖZER

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SUPERVISOR

Prof.Dr. Ender Kazazoğlu

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	Title, Name-Surname (Institution)
Chair of the Jury and Supervisor:	Prof. Dr. Ender Kazazoğlu Yeditepe University
Member/Examiner:	Prof. Dr. Mübin Soyman Yeditepe University
Member/Examiner:	Prof. Dr. Hanefi Kurt Bilgi University
Member/Examiner:	Prof. Dr. Muzaffer Ateş Medipol University
Member/Examiner:	Dr. Yunus Emre Özden Yeditepe University

APPROVAL

This thesis has been deemed by the jury in accordance with the relevant articles of Yeditepe University Graduate Education and Examinations Regulation and has been approved by Administrative Board of Institute with decision dated and numbered ....

Prof. Dr. Bayram YILMAZ

Director of Institute of Health Sciences

DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

09.02.2023

Dt. Ilgın Özer

DEDICATION

I dedicate my thesis to my beloved family and my dear son Pablo…

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I would like to express my endless gratitude to my dear family; my mother Aynur ÖZER, my father Mehmet Ali ÖZER and my idol, my brother Ilgaz Özer, who stand behind me in all circumstances and surround me with their love and support. I am here where I stand now thanks to them and their endless belief in me.

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LIST OF ABBREVIATIONS AND SYMBOLS

3D	Three-dimensional
µm	Micrometer
ADA	American Dental Association
AWS	Active Wavefront Sampling
CAD/CAM	Computer-aided design/ Computer-aided manufacture
CE	Complete edentulism
CMM	Coordinate measuring machine
CCD	Changed Coupled Device
IA	Implant analog
IDS	International Dental Show
IFDP	Implant-supported fixed dental prosthesis
IGES	Initial Graphics Exchange Specification
IOS	Intraoral scanner
LED	Light Emitting Diode
Mm	Millimeter
PE	Partial edentulism
PEEK	Polyether ether ketone
PLY	Polygon file format
POI	Point of interest
RM	Reference model
RMS	Root Mean Square
SD	Standard deviation
SI	Single implant
STL	Standard Tessellation Language
USA	United States of America
VPS	Vinyl polysiloxane

ABSTRACT

Özer I. Three-Dimensional Accuracy Comparison of Digital and Conventional Impression methods in Full-Arch Implant Impression. Yeditepe University Health Science Institute, Department of Prosthodontics, PhD Thesis, Istanbul 2023. The aim of our study was to evaluate the trueness and precision of intraoral scanners and conventional method to be used in implant supported prosthetic treatments. Complete edentulous polyurethane lower jaw model with 6 implants placed both angled and parallel was used as a reference model. A digital reference model was created with the help of a CMM (Contura G2 10/16/06 RDS; Carl Zeiss Industrielle Mess Technik GmbH Coordinate measuring machine). Reference model was scanned 10 times each with 5 different intraoral scanners (3Shape Trios4, Planmeca EmeraldS, Itero Element 5D,3Disc Heron, Primescan) available in the market and digital data were created. 10 conventional impression (Elite HD, Zhermack Spa, Italy) were also taken from the reference models and the plaster models obtained from the impression were scanned with an industrial reference scanner (3Shape 3E Lab Scanner, Copenhagen, Denmark) and data in STL format were obtained. All digital data were registered in a reverse engineering program (Geomagic Control X, Geomagic, USA). Statistical analyses performed using the IBM SPSS software version 28. The Mann-Whitney U test was performed to test the significance of pairwise differences using Bonferroni correction adjust for multiple comparisons. As a result, the median deviation values of the Primescan group and Itero Element5D group were found to be statistically significantly lower than the deviation values of the Emerald S-Planmeca group, Heron ios-3disc group and conventional impression group. (P<0,05) The median deviation values of the conventional impression group were found to be statistically significantly lower than the deviation values of the Heron ios-3disc group. (P<0,05)

In this in vitro study, the accuracy of the digital and conventional impression making approaches for dental implants seems to be clinically acceptable and can therefore be considered applicable for full-arch, multiple implant restorations.

Keywords: Digital Dentistry, Digital Impression, Implant Impression, Intraoral Scanner, Accuracy

ÖZET

Özer I. Tam Ark İmplant ölçülerinde dijital ve konvansiyonel ölçü Yöntemlerinin Üç Boyutlu Doğruluk Karşılaştırması. Yeditepe Üniversitesi Sağlık Bilimleri Enstitüsü Protetik Diş Tedavisi Anabilim Dalı, Doktora Tezi, İstanbul 2023. Çalışmamızın amacı, implant destekli protetik tedavilerde kullanılacak ağız içi tarayıcılar ile konvansiyonel yöntemin doğruluk ve hassasiyetini değerlendirmektir. Çalışmamızda, açılı ve paralel yerleştirilmiş 6 implantlı tam dişsiz poliüretan alt çene modeli referans model olarak kullanılmıştır. Referans modelden CMM (CMM Contura G2 10/16/06 RDS; Carl Zeiss Industrielle Mess Technik GmbH -Koordinat ölçüm makinesi) yardımıyla dijital bir referans model oluşturuldu. Referans model piyasada bulunan 5 farklı ağız içi tarayıcı (3Shape Trios4, Planmeca EmeraldS, Itero Element 5D,3Disc Heron, Primescan) ile 10'ar kez taranarak dijital veriler oluşturuldu. Referans modellerden ayrıca 10 adet konvansiyonel ölçü alınmış ve ölçüden elde edilen alçı modeller endüstriyel referans tarayıcı (3Shape 3E Lab Scanner, Kopenhag, Danimarka) ile taranarak STL formatında veriler elde edilmiştir. Tüm dijital veriler bir tersine mühendislik programı (Geomagic Control X, Geomagic, ABD) ile sanal ortamda kaydedilmiştir. İstatistiksel analizler IBM SPSS yazılımı sürüm 28 kullanılarak gerçekleştirilmiştir. Çoklu karşılaştırmalar için Bonferroni düzeltmesi kullanılarak ikili farklılıkların anlamlılığını test etmek için Mann-Whitney U testi yapılmıştır. Primescan grubu ve Itero Element5D grubunun medyan sapma değerleri, Emerald S-Planmeca grubu, Heron ios-3disc grubu ve konvansiyonel ölçü grubunun sapma değerlerinden istatistiksel olarak anlamlı derecede düşük bulunmuştur. ($P<0,05$) Konvansiyonel ölçü grubunun medyan sapma değerleri Heron ios-3disc grubunun sapma değerlerinden istatistiksel olarak anlamlı derecede düşük bulunmuştur. ($P<0,05$)

Bu in vitro çalışmada, dental implantlar için dijital ve geleneksel ölçü alma yaklaşımlarının doğruluğu klinik olarak kabul edilebilir görünmektedir ve bu nedenle tam ark, çoklu implant restorasyonları için uygulanabilir olarak kabul edilebilir.

Anahtar Kelimeler: Dijital Diş Hekimliği, Dijital Ölçü, İmplant üstü ölçü, Ağız içi Tarayıcı, Hassasiyet

1. INTRODUCTION

In the Glossary of Prosthetic Terms, Impression is "a negative copy of the surface of any object; In dentistry, it is expressed as a trace of teeth and surrounding tissues (1). Shillingburg defines an impression as a trace or negative image of an object (2).In summary, If the restoration is tooth-supported, the impression is defined as "the process of recording the shapes and relationships of the teeth, hard and soft tissues in the mouth, or obtaining negative copies outside the mouth." In the case where the abutments are implants, and an implant-supported restoration will be made, the process of transferring the 3D position of the implant or implants, their relationship with the hard and soft tissue and each other, to the laboratory is called an impression. This transfer can be done digitally and in conventional ways through impression material and devices (3).

The first stage of all prosthetic treatments is the impression session. In dentistry, prosthetic restorations are performed on models identical to the related tissues and neighboring tissues. In prosthetic dentistry, taking a highly accurate impression is the key to obtaining a compatible prosthetic restoration. With the impression obtained, intraoral structures are transferred to the outside of the mouth. Since the quality of the impression affects the fit of the prosthesis, the quality of the impression is critical in terms of the longevity of the prosthesis. The preferred impression technique and impression material also affect the harmony and success of the restoration (4).

Due to the increasing prevalence of implant-supported fixed prostheses, "impression" accuracy has become more crucial. One of the most critical factors in the long-term clinical success of implant-supported fixed prosthetic restorations is the passive fit of the restoration. After the fixed restoration constructed on abutments, if it does not create a static load on the prosthetic system or the surrounding bone tissue, this is called passive fit. In other words, the absence of tension between the abutment and infrastructure is called "passive fit" (5).

For the restoration to be a passive fit, the position of the teeth or implants in the mouth must be transferred to the model in 3D in an exact way. In other words, the impressions must be taken correctly. For the correct impression, the correct impression technique selection, the appropriate impression material, and the relationship between the teeth and neighboring structures must be meticulously recorded. Errors in any of these stages can adversely affect the subsequent laboratory steps, and slight mismatches can cause stress accumulation on and around the abutment (6).

The passive fit of restorations is dependent on two factors known as "trueness" and "precision." Trueness term defines the deviation of the impression geometry from the original geometry. In other words, it is defined as "the closeness of deviations between the arithmetic mean of a large number of test results and the true or accepted reference value." Another factor that affects the passive fit is precision. Precision: is "the closeness of agreement between measured quantity values obtained by replicate measurements on the same objects under specified conditions": it refers to the closeness deviations between test results (7).

Various impression methods have been developed to increase the accuracy of impressions taken for prosthetic restorations. Changing the physical and chemical properties and application methods of the impression materials used with the advancing technology helped the development of conventional impressions in order to get optimum levels. Among the Conventional impression materials used, Polyether and Polyvinyl siloxane impression materials are frequently used in the clinic due to their superior properties (5). Today, new impression materials are being introduced to the market with the developing technology. Polyvinylsiloxanethers are impression materials created by combining the favorable properties of polyether and polyvinylsiloxane-based impression materials (8) (5).

With the development of intraoral scanners used in the digital impression, the digital age in dentistry has started (5). The use of intraoral scanners had very limited indications, such as single crown treatment when they were first manufactured. Today, studies are showing that intraoral scanners can be used in the impression phase of implant-supported fixed prosthetic treatments in edentulous patients (9) (10).On the other hand, the trueness and precision of intraoral scanners and the passive fit of prostheses produced according to these impressions are currently the subject of research (10) (11). Some studies demonstrate the advantages and disadvantages of intraoral scanners over conventional impressions (12) (13). Intraoral scanners of different manufacturers and models are compared among themselves for various indications. With the help of these progressive works, the limitations of scanners are revealed, and these limitations are tried to be eliminated by improving scanners (14) (15) (16).

There are two different approaches to assessing the precision of impression methods. The first is to evaluate the fit of the fabricated restoration on the master model. The other is to compare the virtual model obtained by the impression with a highly accurate reference dataset (the master model). Three-dimensional discrepancies between the two-surface data can be analyzed by superimposition using appropriate software (17).

The use of digital impressions in dental practice is progressing rapidly. It is under development with additional innovations to solve the problems that arise. The scanners developed for use in the impression phase have different operating principles and therefore have their limitations. It is still being determined which type of scanner is best for which conditions. Although various parameters have been considered in studies evaluating the accuracy of digital measurements, the number of scanning devices is often limited. Moreover, it is unpredictable how these devices will behave in which cases.

Our study aimed to evaluate the trueness and precision of intraoral scanners and the conventional method to be used in implant-supported prosthetic treatments.

The first null hypothesis is that there is no significant difference in trueness between the digital and conventional impression methods, and intra-oral scanners have similar trueness values. The second null hypothesis is that there is no difference in deviation values between implant groups according to their angles for each impression method.

2. GENERAL INFORMATION

2.1. Impression methods for implant supported protheses

The impression process refers to obtaining a complete negative of the preparation area, the inside of the mouth or any region with various materials and applications (1). If the restoration to be made is tooth-supported, the impression is defined as "the process of recording the shapes and relationships of teeth, hard and soft tissues in the mouth or obtaining negative copies of them outside the mouth," whereas in an implant-supported restoration where the abutments are implants In the case of restoration, the process of transferring the 3-dimensional position of the implant or implants and the relationship between hard and soft tissue to the laboratory is defined as an impression (18).

Impressions should be as close as possible to the actual values, easy, fast and comfortable for the patient and clinician. Impressions can be obtained with conventional or digital techniques. Although digital impression techniques are becoming more and more widespread today, conventional impression techniques are still used extensively to take impressions of implant prostheses. In the conventional technique, the impression material to be used is placed in the patient's mouth with the impression tray, and the impression tray is removed from the patient's mouth after the impression material has been set. Despite the widespread use of digital impressions of implants due to the recent development of ti-base sets, scan body types, and digital mouth scanners, there still needs to be more data on digital impression accuracy in cases with full arc implant cases (19).

The impression phase of implant-supported prostheses must be faultless because; It is vital to provide a passive compatible superstructure, which is essential for the clinical success and prognosis of implant-supported prostheses (20).

According to the researches, there are many factors affecting the impression accuracy in the 3D transfer of the implant positions to the model can be listed as:

- İmpression technique
- Impressions in implant level and abutment level
- İmpression material

- Number of implants and angulations
- Implant placement depth
- Implant-abutment connections

(20) (21) (22) (23)

2.1.1. Conventional impression materials for implant-supported prostheses

The ability to obtain an impression of implant prostheses accurately is an important factor affecting the success of the implant in the long term. In the past, polysulfide-based materials and condensation silicone were used to make the most precise impression of implants. Polyvinyl siloxane and polyether-based impression materials are now recommended (19).

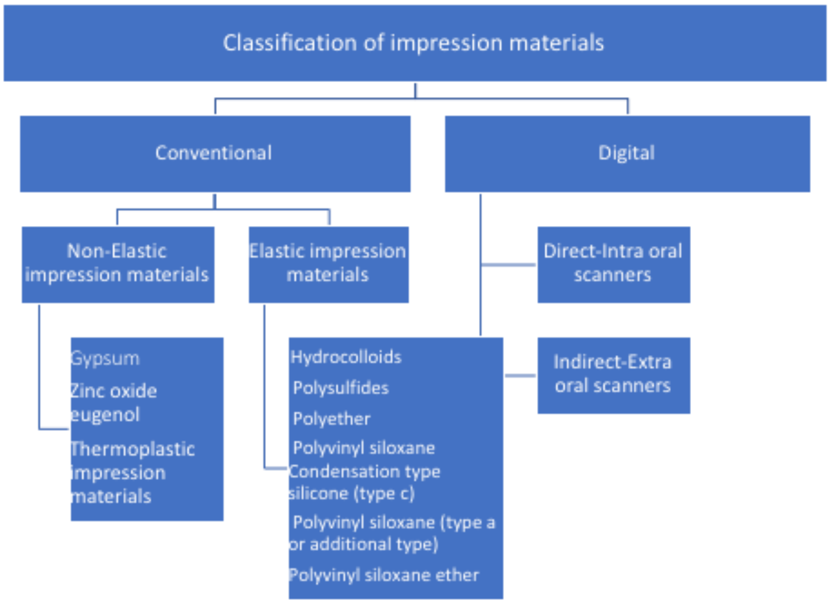


Figure2. 1 Classification of impression method

2.1.1.1. Polysulfides

Polysulfides, available in two tubes, base and catalyst, have been used for their high accuracy and relatively low cost. They are available in different flowability levels. The base component includes polysulfide, plasticizer and filler, while the catalyst component includes reaction initiator (lead dioxide), copper and organic dioxides, modifier (sulfur), and form former (dibutyl phthalate, reactive oils). They have a long working life, high tear strength, good surface detailing and high stretch ability. Their low viscosity is the main factor that makes their use difficult. In addition, their unpleasant odor can be disturbing for patients (24) (25).

2.1.1.2. Polyether

Polyether, which was introduced in the late 1960s, is available in two pastes and has low, medium and high viscosity forms. The base contains polyether, colloidal silica, and plasticizer, while the catalyst contains aromatic sulfamic acid ester, thinners and fillers. Their reaction is an addition-type reaction, with no formation of by-products. Its stretching properties are limited, it has a very hard structure after polymerization. For this reason, especially in undercut areas, tears may be encountered when removing the impression from the mouth. They are superior in terms of dimensional stability. They retain their form for up to 1 week under dry storage. Due to their hydrophilic structure, they are highly detailed and easy to cast plaster in model making (25) (26) (27).

2.1.1.3. Polyvinyl siloxane condensation type silicone (Type c)

They are mainly used in fixed prostheses. They are available in different viscosity forms; low, medium, high and very high (putty). Putty-putty or Putty-Liquid catalyst systems are available. The base content includes dimethyl siloxane polymer, crosslinkers and fillers, while the catalyst content includes organic metal esters, thinners. They are named because they are polymerized by the condensation reaction. This reaction produces alcohol as a residual product. After the impression is taken, shrinkage occurs due to the evaporation of this alcohol and the maintenance of dimensional stability in condensation-type silicones is insufficient. They should be poured out immediately after removal from the mouth. Type C silicones are hydrophobic impression materials. For this reason, the dryness of the relevant area during impression taking is essential, the impression material is limited to show the surface details, and the cast ability of the plaster is difficult when obtaining the model (24) (25).

2.1.1.4. Polyvinyl siloxane additional type silicone (Type A)

Type A silicones, polyvinylsiloxanes, which have become widespread since the 1990s, have become highly preferred due to their superior physical properties, dimensional stability and ease of use despite their high cost. The base materials are polymethyl hydro siloxane containing terminal silane hydrogen groups and inert fillers. The activator contains terminal vinyl groups, chloroplatinic acid and dimethyl siloxane polymer. These groups are polymerized by addition reaction. No by-products are formed, but additional hydrogen groups are formed, and hydrogen is released from the impression material after the impression process. The fact that they do not form residual products as a result of the reaction is the reason for their excellent dimensional stability. They are suitable for obtaining models with multiple castings and can maintain their dimensions for up to 1 week after impression taking. Essentially, type A silicones, which have the primary disadvantage of being hydrophobic, have been made hydrophilic by the addition of surfactant. Studies have shown that sulfur in latex gloves and rubber covers can inhibit type a silicone polymerization by degrading platinum in the activator content. This can be prevented by the use of vinyl or nitrile gloves. Despite these disadvantages, polyvinylsiloxanes are currently the most preferred impression materials for fixed and hybrid prostheses due to their superior physical properties (25) (24).

2.1.1.5. Polyvinyl siloxane ether

Introduced in the late 2000s, vinylsiloxanether, also known as vinyl polyether siloxane, was developed by combining the properties of polyvinylsiloxane and polyether impression materials Although the combination of the physical properties of polyvinyl siloxane, such as its elasticity, and the hydrophilic properties of polyether, may have a promising profile for areas where moisture control and accessibility are difficult, such as subgingival areas but more studies are needed to evaluate this situation (8) (28).

2.1.2. Conventional implant supported protheses impressions methods

Only one-stage impression methods can be used in the production of implant-supported prostheses. Conventionally, implant impressions are obtained from either direct (open tray) or indirect (closed tray) techniques (29) .

The most commonly used conventional impression materials in the studies have been reported as additional type silicones (PVS) and polyether impression materials (30). Impression materials should have a level of rigidity to prevent displacement of impression analogs used in the implant impression during removal from the mouth. Polyether impression material has high rigidity, this is one of the reasons that polyether frequently used in implant impression (31) . Polyether is a relatively has more hardness value and compared to PVS and can theoretically reduce the amount of permanent deformation that will occur in the impression compared to an impression material such as PVS with high yield strength and low elastic modulus. Further, the PVS impression material aids in easy removal of the set impression owing to its suitable modulus of elasticity; thus, it has been suggested as a preferred material for the direct implant impression technique (32) (31).

2.1.2.1. Closed tray technique (Indirect)

It can be used in cases where the number of implants is 3 or less and the implants are relatively parallel to each other. There is no need to prepare individual trays. Tapered copings and analogs that match the height of closed tray mostly used in this technique. Subsequently, heavy body impression material is injected around the impression coping and into the tray, performing an impression that is then separated from the mouth, leaving the copings intraorally. The copings are then removed from the implants, connected to implant replicas, and positioned in its corresponding place in the impression. Finally, the assembled set is sent to the laboratory (33) (29).

2.1.2.2. Snap-on (Press fit) technique

It is a method in some implant system which uses plastic impression caps in closed tray impression technique. These impression caps can be used as an alternative in cases where the implants are placed very close to each other or where the implants are placed at multiple angles. The press-fit impression coping is easier to manipulate, time saving and more comfortable for both patient and clinician because the coping is connected to the implant by pressing instead of screwing. However, during the removal of the impression from the mouth, the micro-movements that can be caused by the stretching of the plastic cap which placed in the impression material can be listed as the disadvantage of the technique. On the other hand, in some cases where the implants are placed close to each other, the snap-fit impression caps cannot be properly seated on the implant, and even may cause problems such as loss of retention and repeating the impression during impression taking. In these cases, the use of the open tray impression technique may be preferred (33) (34).

2.1.2.3. Open tray technique (Direct)

This technique preferred in the presence of non-parallel implant positions on the same arc or in cases where bilateral multiple implant applications are applied. Individually fabricated custom trays and square shaped, angular and long pieces are used in this technique. There holes in the custom fabricated trays (a tray with an opening) which allows the coronal ends of the impression coping screw to be exposed. Before separating the implants, the copings screws are unscrewed to be removed along with the impression. The implant analogs in the impression are connected to the copings to fabricate the definitive cast. The disadvantages of this technique could be that there may be some rotational movement of the impression coping when securing the implant analog, and blind attachment of the implant analog to the impression coping may result in a misfit of components. In order to prevent these problems, splinting of the impression transfer copings to each other has gain popularity. The main purpose of splinting is to prevent possible movements that may occur in the impression material by connecting the impression posts with a rigid material and splinting them (34).
Among the materials used for splinting impression pieces;

- Acrylic resins (35) (36)
- Impression plasters (35)
- Dual-cure acrylic resins (37) (35)
- Orthodontic wires (36)
- Prefabricated acrylic resin bars (37) (38)
- Carbon steel pins (36)
- Light-curing composite resins are available (35)

In cases such as limited mouth opening, gag reflex, implant position that is very difficult to reach, it is not possible to take impression with direct method, and in such cases, it is recommended to take impression with the indirect method (30) (39) (40) (41).

2.1.3. Implant or Abutment level impression

2.1.3.1. Implant level impression

After the healing caps are removed, in the implant-level impression technique, the impression copings are connected to the implant, and then the impression is obtained with the open or closed tray method. Among its advantages, it can be shown as ease the fabrication of temporary restoration, improving aesthetics, easier abutment selection in the laboratory environment and in order to achieve better angulations with the angled position implants position with the help of angled abutments (42) (43).

2.1.3.2. Abutment level impression

The abutment, which is selected in accordance with the angle, diameter and length, is torqued directly to the implant and impression is obtained over that structure with the help of plastic caps similar to Snap-On method. In this impression technique, the sensitivity of the sense of touch and the proper placement of the locking mechanism of the plastic part are of great importance (39) (44).

2.1.4. Digital impression

Conventional impression methods have served for many years in the production of prosthetic restorations when ideal instructions are followed. CAD-CAM systems have been developed in order to minimize the risks that may occur during the steps during the acquisition of conventional impressions and reduce the number of production stages of prosthetic restorations. With the help of rapidly developing technology, this technique made it possible to get impression directly from the patient's mouth or to scan the impressions / models outside the mouth and transfer it to digital media. Today, digital dentistry is gradually increasing in popularity and finds widespread use in clinical applications. Especially in the last 10 years, a serious competition has emerged with many different dental companies producing intraoral scanners and putting them on the market with different brands (45).

The first visualization of intraoral tissues on the computer with optical readers was first provided by Bruce Altschuler in 1977 in the USA. Computer aided design / computer aided manufacturing (CAD/CAM) has developed greatly in dentistry since the 1980's. Francois Duret developed the Duret system in 1984 and produced single unit restorations. Werner Mörmann and Marco Brandestini from Switzerland performed the first dental CAD/CAM application with the Cerec system in 1988 with the benefits of production cost and applicability (46) (47).

The basic working principle of CAD/CAM systems used in the production of prosthetic restorations consists of 3 stages. In the first phase of digitalization; It is aimed to transfer the data obtained from mouth to digital media. In the second stage; design of the planned restoration to be made on the digitally obtained 3D models are carried out (CAD). In the last step; 3D production (CAM) of the designed restoration is carried out (48).

Figure2. 2 Workflow of CAD/CAM

2.1.5. Functional elements of CAD/CAM systems

Dental CAD/CAM systems; It consists of three functional elements: optical (digital) or mechanical scanner, software program and production element (fabrication) (49).

2.1.5.1. Design software program (CAD)

Restoration designs are made on the digital models by using special software. There is various software to make these designs. In automated systems, the restoration designed by the software can be reshaped according to the user's own preference. When the software design is complete, it converts the prepared model to a special series of commands. Just like scanners, softwares are unique to CAD/CAM systems and cannot be interchangeable (49).

2.1.5.2. Fabrication (CAM)

CAM is where the computer-controlled forming of the designed restoration is produced by the subtractive, additive method or the combination of these two systems. The first CADI/CAM systems used milling systems with diamond burs or diamond disks to produce restoration from prefabricated blocks. In this technique called 'subtraction method', the block material is subtracted to achieve the desired shape. Although this method is effective, 90% of the prefabricated blocks are removed to obtain a typical dental restoration and thus wasting most of the prefabricated block material (49) (50).

As an alternative to the subtraction method, nowadays there are production systems by adding 'rapid free-form fabrication' such as rapid prototyping (3D free- form fabrication). Selective laser sintering is one of the methods used for the production of ceramic or metal restorations. In this method, a restoration computer design uses a process sequence similar to the cutting process in existing CAD/CAM systems. However, instead of cutting, during the process sequence, the material in the ceramic or metal powder pool is continuously sintered to complete the restoration. Thus, there is no residual material wasted. Stereolithography is also an additive system which can be used to produce occlusal splints, surgical guiding plates and working model. Some CAD/CAM systems like Procera (Nobel BioCare, Goteborg, Sweden) uses a combination of addition and subtraction methods (49) (50).

2.1.6. Digital Data Acquisition with CAD / CAM Systems – Digitalization

For existing CAD/CAM systems, it is possible to use a touch pin, laser distance meter, linear laser beam scanner with a CCD (charge coupled device) camera for obtaining data. It is possible to scan the models, impressions, or intraoral tissue. When using a probe (contact scanner) that touches the surface of the area to scan, it takes a long time to scan the model. The laser distance meter is relatively fast and economical, but the sensitivity decreases due to the detecting of the rays reflected from the beam being sent by the PSD (position sensitive device) sensor. Therefore, scanning for sharp edges and corners presents difficulties. The resolution of the CCD camera is a factor that affects the sensitivity. None of these methods can be measured on surfaces with undercuts (45) (51).

It is possible to obtain digital impression, by using the scanners used in data acquisition in two ways, direct and indirect methods.

2.1.7. Indirect methods

Impressions are obtained with conventional impression materials and methods. A virtual model can be obtained by scanning the obtained impressions or the models scanned with an extraoral scanners. The desired restoration can be designed on the virtual model. It is not possible to create healthy digital data from the surface of traditional impression materials (52) (53).

2.1.8. Direct methods

There are 2 types of scanners in dentistry that can be used in tactile (contact) and non-touch (non-contact) mode. Visual software prepared with tactile (contact) systems are obtained by simply touching the scanner tip to the object to be scanned. Non-contact scanners are generally available in active and passive forms. Passive ones work on the principle of detecting the radiation they emit into the environment. For this reason, passive form scanners are not currently used in the dental sector. Touchless 3D scanners used in dentistry are in active form. They emit various types of radiation, such as light, ultrasound (US) or X-rays, and capture the light reflected from the object to be imaged (54) (55).

After the digital impression is obtained, the surface configuration is performed using the point cloud obtained on the scanned object surface. This process is carried out by the algorithm in the software specially produced for the intraoral scanner by sorting, organizing and combining these point clouds into a single image, thus obtaining a 3D model of the scanned object (56) (57) (58).

The high density of point clouds in the region allows the software to perform the surface processing algorithm with high precision. Thus, a 3D digital model similar to the real object surface is obtained. After the impression, some surfaces have insufficient point clouds due to insufficient scanning and the software reconstructs this surface by itself. The reconstructions performed by the software in these unscanned regions can often vary significantly compared to the actual volume, resulting in various dimensional variations in size (59) (60).

The surfaces in the digital model are defined as STL (Standard Triangle Language) files, and the size of this file can vary both between intraoral scanning systems and between different scans using the same system. This type of format is the most commonly used in industrial areas and is based on the 'triangulation' of surfaces by means of triangles formed by three defined points and a surface. However, other formats, such as Polygon File Format, PLY files, have been developed to record color, translucency or properties of dental tissues. Regardless of the technology used by the intraoral scanner, individual images or videos need to be compiled by the software after POI recognition (points of interest) in all cameras The first two coordinates (x,y) of each point are evaluated on the image and then the third coordinate (z) is calculated based on the distance of the cameras from the object (61).

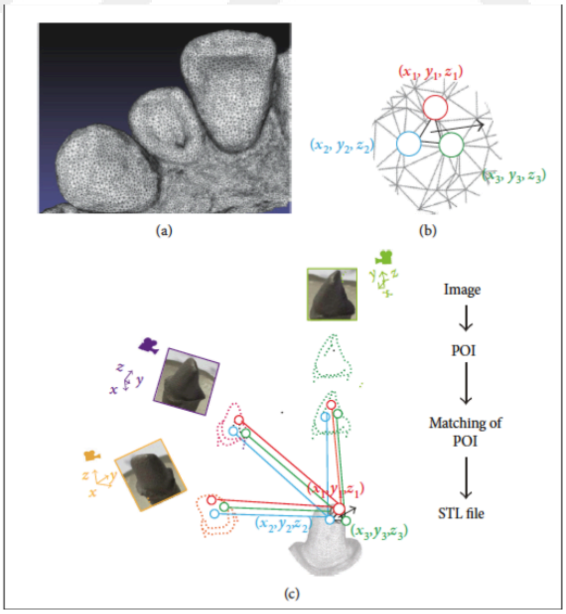


Figure2. 3 Production of STL files obtained from an intraoral scanner. (a) An example of the STL format. (b) Each triangulation in the STL file consists of three points with specific coordinates and a surface. (c) Schematic representation of the reconstruction technology: Each image is analyzed and points of interest (POI: points of interest) are selected by the software. After a similarity calculation between different images, overlapping POIs are matched and triangles with coordinates are generated by the projection matrix.

Current intraoral scanner technology is not equipped to obtain a 3D model of the entire arch with a single imaging. For this reason, it is possible to digitalize the intraoral structures by obtaining many different images and combining these images by superimposing them. Depending on the technique used to obtain these images, intraoral scanners are basically divided into two groups; scanners that take digital photographs, combine them and create a series of photographs or scanners that create these images with digital video method (62) (63).

Intraoral scanners send beams of laser or structured light onto the surface of the object to be imaged. They then use two or more cameras to detect the deformation that the beams are subjected to on that surface and perform 3D coordinate calculations thanks to their powerful processors and software. The software performs a 3D reconstruction of the scanned surface thanks to the point clouds and meshes it produces. The software detects thousands of points per second, processes them and combines the resulting images appropriately to produce a 3D model. However, one of the biggest dimensional changes encountered in digital impression occurs when images are combined with each other (64) (65).

However, different intraoral scanners manufactured by different companies work with different protocols such as confocal microscopy, triangulation, interferometry, wave front sampling, structured light, laser and video. Due to these working principles, there can be serious differences between the image accuracy they produce (59).

Depending on the use of the intraoral camera by the operator, object surfaces can be visualized with different intensities. For this reason, when the same object is scanned by different operators or at different times, different intensities can be obtained, resulting in inaccurate surfaces in 3D models (66).

Besides photography and video recording intraoral scanners can be grouped according to their image digitization algorithms and operating principles (63).

Working principles of intraoral scanning cameras can be classified as follows:

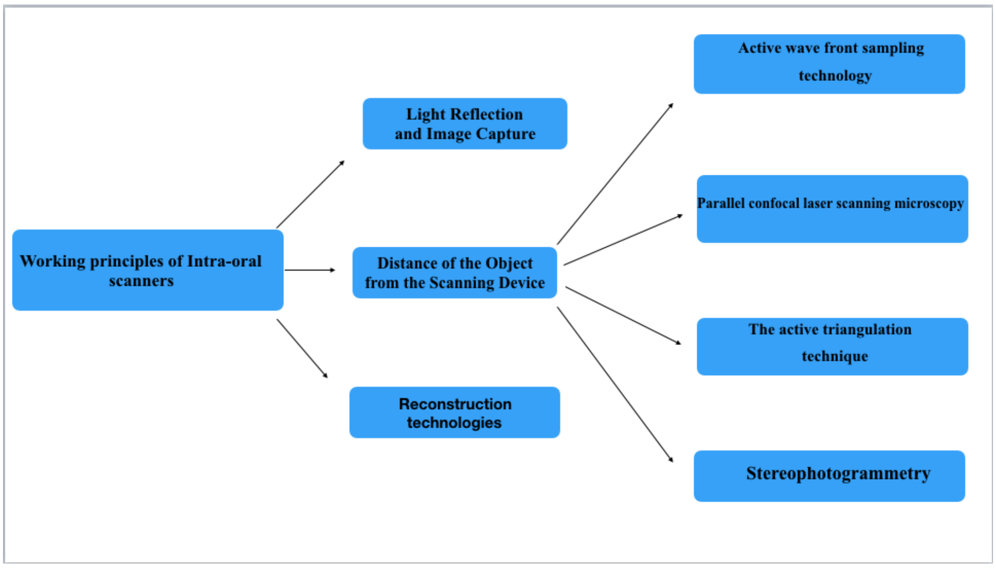


Figure2. 4 Working principles of Intra oral scanners

2.1.8.1. Light Reflection and Image Capture

Passive and active techniques are used to create the three-dimensional image. In the passive light reflection technique, the intraoral tissues are illuminated only by ambient lighting and depend on the surface structure of the object. The active light reflection technique uses blue, red or white light from the camera (light source) to project onto the object, which is less dependent on the surface structure of the objects. In the active technique, the bright spot is projected onto the object and its distance to the object is calculated by triangulation. Another way is to project light in the form of a line or a net instead of a dot. A three-dimensional image of the surface can be obtained with a large number of photos or videos taken in one second (61).

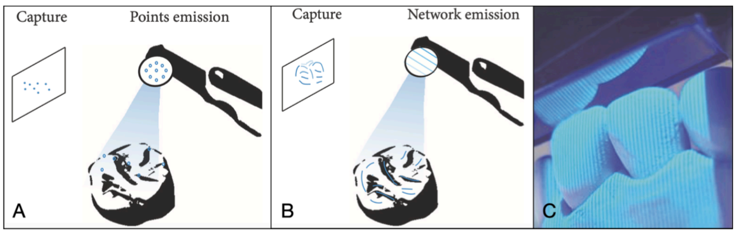


Figure2. 5 Projection of the points (A), Projection of the mesh (B), Projection of the mesh with intraoral scanner (C) **(61)**

2.1.8.2. Distance of the Object from the Scanning Device

1- Active wave front sampling technology
2- Parallel confocal laser scanning microscopy
3- The active triangulation technique
4- Stereophotogrammetry

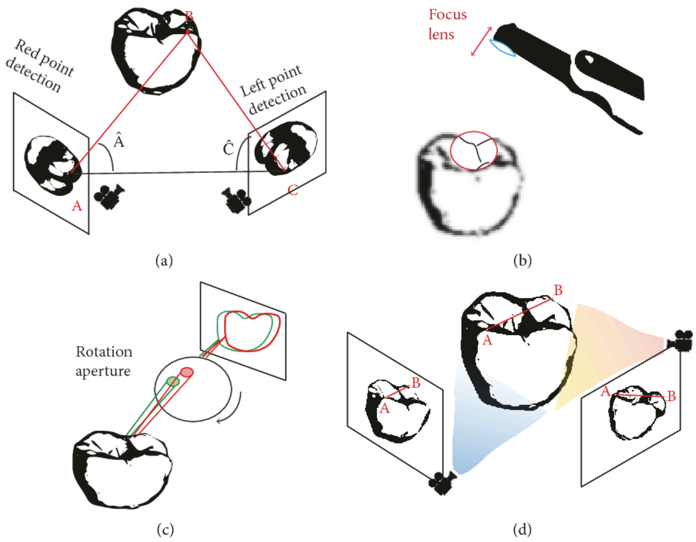


Figure2. 6 Determining the object distance. (a) Triangulation: The distance BC can be calculated with the formula BC= AC x sinÂ/ sin (Â + C). (b) Confocal: The distance to the object is determined by the focal distance. (c) AWS requires a camera and an off-axis that moves in a circular path around the optil axis and allows rotation at points of interest. (d) Stereophotogrammetry is a technology that produces files by analyzing a large number of images algorithmically.

Active wave front sampling technology 3D-in-motion video recording

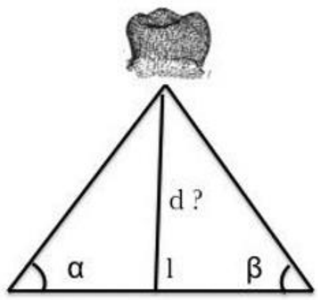
In this system, data digitization is performed by simultaneous video recording with a lens with a rotating aperture with a structured blue light projection in the front. 3D-in-motion video is recorded by the high definition video cameras, The high definition cameras placed in the scanner captures the object from different angles and the system calculates three-dimensional coordinates in space of the object using this data and finding the spatial distances and creating the digital objects in real time . it requires a very light dusting with a scanning powder to reduce light reflection and, more importantly, to enhance the connection between captured images in the scanning process. Lava C.O.S. developed by 3M. can be count as example using this technology (67) (68) (69).

Parallel confocal laser scanning microscopy

The term confocal can be explained as having the same focal point. They are based on the optical system available in confocal microscopes. This optical technique to attain images from selected depths. The parallel laser beams are emitted from the camera, then reflected from the target surface and returned to the same optical path. (69) Light beams with the same focal point reflected from the object return through the filter of the system and form a three-dimensional image of the object, while the light beams with different focal points cannot pass through the filter. the whole 3D object is reconstructed by retrieving 2D images at different confocal planes. this imaging process is also known as “point-and-stitch reconstruction.”. However, this system is slower if we compare it with active wave front sampling technology. There is no need for scanning powder application in this system. The parallel confocal technique allows capturing the images in color and without scanning powder application. It allows imaging of dental tissues such as dentin, enamel, dental materials such as amalgam, gold, ceramics, composite resins and soft tissues with the same sensitivity. This system was originally developed by iTero (Cadent - Align Technology Inc.). iTero and TRIOS are the two scanners that use this technique (69) (67).

The active triangulation technique

The purpose of this technique is to calculate the distance of a point from two known points and its position in space based on the angles it makes with these points and the known distance between two points. Triangulation theorem (Figure2.7) is also frequently used in trigonometry and geometry. The light source emits either monochromatic light (CEREC AC Bluecam) or light with different wavelengths (CEREC AC Omnicam), which reflects from the target and is recorded by CCD (Charged Coupled Device) video sensors. The distance between the sensor and the light source is known, and the coordinates of the imaged object in space can be determined based on the angles that both elements make with the light beams. The CEREC AC Bluecam IOS requires scanning powder applications and performs colorless scans. On the contrary, CEREC AC Omnicam IOS does not require any scanning powder application and performs true color scans (69) (68).



$$d = \frac{l \cdot \sin\alpha \cdot \sin\beta}{\sin(\alpha + \beta)}$$

Figure2. 7 Triangulation theory

The biggest problem encountered in devices working with this principle is the 'distal shadow phenomenon (Figure2.8). The phenomenon of a distal shadow is explained as the beam the camera reflects on the object, creating a shadow on the object's distances, affecting the sharpness of the image. This shadow is only observed on the distal surface. the effect of a distal shadow on an image increases as the object's height increases and the conic angle decreases (70).

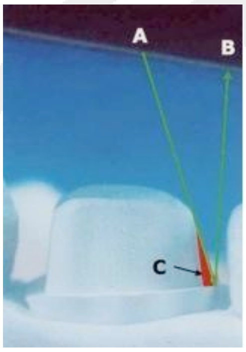


Figure2. 8 Distal shadow phenomenon (A. Light reflected on the object B. Light reflected from the object C. Distal shadow.)

Stereophotogrammetry

Stereophotogrammetry calculates all coordinates (*x*, *y*, and *z*) only through an algorithmic analysis of images as this method relies on passive light projection and software rather than active projection and hardware, the camera is relatively small, its handling is easier, and its production is cheaper (61).

2.1.9. Advantages of the digital workflow with different IOSs and compared them to conventional workflow:

Real-time imaging for a better detection of the critical impression details: The clinician can see the scanned area simultaneously during the scan and has the chance to intervene immediately on the missing points (64) (69) (71).

Easy repeatability: If there is a large part of the impression is wrong, it can completely delete the existing data and scan again, and this process is much more practical compared to the conventional method (69) (64) (71).

Easy to make addition: Virtual cutting tool for inadequately scanned areas and the possibility to incorporate an additional selective scan (69) (64) (71).

Color: Some of the systems can also make color selection with the scanner and transfer this information to the desired laboratory. It's easy to recognition of the tooth and gingival structures with color mode (71) (69) (64).

Chairside analysis of the performed preparations: Variables such as material thickness, access path, cement spacing can be realized in a much more practical way in the digital environment during the design phase (64) (69) (71).

Chairside CAD/CAM option: Digital data may be linked to "in-Office" systems. Without the need to send the impressions to any laboratory, restorations can be designed and produced quickly with milling devices in house (71) (64) (69).

Patient comfort: It has been shown that patients find the digital measurement more comfortable than the traditional measurement. In addition, it was stated that the time spent taking the digital impression was statistically significantly less than the time spent for the traditional measurement (72) (69) (64) (72).

Time efficiency: Intra oral scanners enable reduction of the working times (12) (64).

Connection ability: It allows to have a possibility of connect the intraoral scan and computer tomography/digital volume tomography or extraoral face scan and work in virtual environment with all of that data (64) (69) (71).

Monitoring: It allows to have Possibility to monitor the follow-up of systematically performed intraoral scans over time (71) (64) (69).

Easy communication with the patient and dental technician: Data can be sent simultaneously to the desired laboratory via e-mail, CD, external disk or internet. The procedures done and procedures plans the can be explained to the patients more easily visually (69) (64) (71).

Conventional material savings: No material wastage as no impression material is used. optical impression allows the skipping of a casting gypsum models. It reduces consumable costs (64) (69) (71).

No model deterioration : In the conventional method, situations such as using the wrong tray and impression material, distortion of the impression material while taking it out of the mouth, separation or tearing of the impression material, and the urgency of pouring the impression materials according to the type are also eliminated on a digital impression (64) (69) (71).

Storage: All kinds of scan data about patients (digital impression, bite record, restoration, tooth color, designs ...) can be easily stored on the computer and transferred to another external disk or CD when necessary (71) (64).

Articulator: After the digital impressions and bite records are taken, the digital systems combine these data so that the models do not need to be connected to the articulator, as is practiced in the traditional method (64) (69) (71).

2.1.10. Disadvantages of the digital workflow with different IOSs and compared them to conventional workflow:

Investment and managing cost: Depending on the model, purchasing an IOS requires a considerable amount of investment. Another aspect to consider additional managing cost like annual fees or special software costs integrated in IOS systems (12).

Learning curve: Learning to use systems and adapting it into a clinic routine takes time and a lot of attention. There is a learning curve integrating IOS system in the dental routine. Clinicians who has affinity to World of technology and computers will find it easier to adopt. Another aspect to consider, there is still arguments about which scanning protocol is better. It is possible to produce different results with different machines and different scanning protocols (12).

Difficulty detecting deep margin lines: It does not compensate for errors as much as conventional impression methods. Subgingival margins or irregularity in margins may cause problems both in scanning and design phases. Factors such as saliva and blood in the environment should be removed and a good isolation should be provided. Saliva or blood may obscure the prosthetic margins (12).

2.1.11. Intraoral Scanners Used in Direct Method

- Trios 4 -3Shape (Copenhagen, Denmark)
- Cerec Omnicam -Dentsply Sirona (York, PA, USA)
- Heron ios-3disc (Herndon, VA, USA)
- Emerald S-Planmeca (Helsinki, Finland)
- Primescan-Dentsply Sirona (York, PA, USA)
- Itero Element5D-Align Technology-Cadent (Carlstadt, USA)

Trios 4 -3Shape (Copenhagen, Denmark)

Figure2. 93Shape Trios 4 wireless IOS

3Shape was established in Denmark in the year 2000. The TRIOS system is a complete in-house ecosystem including a scanner and extensive design software. Scanning is done with the principle of 'ultra-fast optical scanning', which is a combination of structured light and parallel confocal microscopy. The scanner has one main button on the top to start and stop the scan. It also has an inbuilt gyro meter which can be used to move any scans around for viewing and navigate the software without having to touch the screen/computer. TRIOS 4 has one of the smaller scanner heads compared to others on the market. It weighs 345g (wired) or 375g (wireless with a battery). The scanner comes in two options: plug and play (called the pod), or the TRIOS Move. The TRIOS Move comes in two options, the MOVE or MOVE + (plus), the difference being the size of touch screen display. 13.3” for the MOVE and 15.6” for the MOVE +. TRIOS 4 is the only wireless scanner on the market. TRIOS scanners comes with an inbuilt heater in the scanner The inbuilt tip heating (which heats to body temperature) prevents fogging of the scanner tip throughout scanning so the operator does not need to worry about having a suction unit nearby or keeping the scanner tip warm to prevent fogging of the scanner mirror. The TRIOS also have an inbuilt fan to keep the scanner itself from overheating.

Figure2. 103Shape Trios 4 MOVE IOS

Crown restorations, bridge restorations, veneers, inlay-onlay restorations, removable partial dentures, temporary restorations, post-core restorations, implant-supported crown-bridge prostheses can be made with the impressions taken with the Trios camera. After the scanning process is completed and a three-dimensional model is obtained, the distance between the prepared tooth and its antagonist can be measured with the occlusal aperture measurement feature of the software. The system shows whether there is enough distance with color codes. The software ecosystem also includes new applications for the design and fabrication of: Implant surgical guides (Implant Studio), Bite splints and night guards (Splint Studio), Clear aligners (Clear Aligner Studio), Orthodontic bracket guides (Indirect Bonding Studio). Caries detection is a new feature to the TRIOS line of scanners found in the TRIOS 4. It has built-in fluorescent technology that aids in the identification of supra-gingival carious lesions, mainly on the occlusal surfaces. All TRIOS and 3Shape products are designed non-exclusively, meaning they all feature open interfaces for connection to third-party applications. The entire system is open and enables the easy transfer of STL files and (more recently) color PLY and DCM files.

Cerec Omnicam -Dentsply Sirona (York, PA, USA)

Figure2. 11 Cerec Omnicam IOS

The CEREC system has the longest history in the CAD/CAM industry. Cerec Omnicam intraoral scanner, which was introduced in 2012 after the Cerec Bluecam scanner, is available in 2 different versions as trolley and tabletop. Working with the principle of active triangulation and confocal microscopy, this device performs imaging with non-polarized white LED light. Omnicam incorporates video streaming rather than stitching of static images. It has a small scanning tip with the size of 228 x 16 x 16 mm, allowing easy scanning in the mouth. Although Cerec Omnicam has a closed system, the virtual data can be converted to STL format thanks to its up-to-date software. This scanner doesn't require any scanning powder application (73).

Emerald S-Planmeca (Helsinki, Finland)

Figure2. 12 Planmeca EmeraldS IOS

Planmeca EmeraldS is an intraoral scanning device that Planmeca company released in IDS2019 after its Emerald scanner. this is not a completely new product; it is instead a number of hardware and software improvements on the previous generation Planmeca Emerald scanner. Planmeca company claims with the EmeraldS they made improvement in the scanning speed compared to Emerald. Scanning is done with the working principle of Projected pattern triangulation, this device performs imaging with Red, green, and blue lasers. It weighs 229 grams, is 249 mm long and stands out for its compact design. It has a small scanning tip with the size of 41 x 45 x 249 mm. There are 2 different scanner heads available including an overdue smaller scanner head called the Slimline Tip and the original scanner tip. The inbuilt tip heating (which heats to body temperature) prevents fogging of the scanner tip throughout scanning. This scanner doesn't require any scanning powder application. Caries detection abilities via the new "Cariosities Tip" which uses transillumination technology. This can be utilized as an additional inter-proximal screening tool (74) (75).

The device is connected to a portable computer with the USB 3.0 feature. Planmeca company offers its users the advantage of an open system. Therefore, data output in STL, PLY format is possible. It is compatible with Romexis 6.0, which is the design and production software of Planmeca. Thus, the obtained impressions can be sent to the laboratory digitally and can work with the design and production units of different manufacturers (74) (75).

Heron ios-3disc (Herndon, VA, USA)

Figure2. 13 3Disc Heron IOS

The Heron IOS by 3disc is an intraoral scanner released to market in 2018. Scanning is done with the working principle of Active stereo imaging with Continuously scans and accumulates (stitching) depth and color data. It designed with 360° rotating tip and a total weight of only 150 grams. The Heron IOS does not requires any scanning powder application. The software that works with the Heron IOS is called HeronClinic. This software functions such as analyzing occlusion or reduction space, editing scans, removing any scan data. Heron IOS is plug and play, you connect it to a suitable laptop/computer by USB and use it. The Heron IOS has an inbuilt fan in the scanner which prevents fogging of the scanner tip.There is no CAD software including in the system but Heron IOS offers open system, data output in STL, PLY or OBJ format is available. It is compatible with the most of the dental CAD systems. The scanner software is set up to aid in the creation of restorations such as anatomic crown, impression copings, inlays, onlays, provisional crown, anatomic pontic, reduced pontic, provisional pontic, veneers, diagnostic wax-ups, bite splints and implant supported restorations (76).

Primescan-Dentsply Sirona (York, PA, USA)

Figure2. 14 Dentsply Sirona Primescan IOS

The CEREC system is complete in-house CAD-Cam system including a scanner, CAD software, milling machine and ceramic furnace. Since the Omnicam IOS entered in dental market and changed the digital dentistry in 2012, CEREC becomes global leader in chairside CAD/CAM dentistry and revolutionized in the field. In 2019, Dentsply Sirona released new lineup of CEREC chairside CAD/CAM equipment: intraoral scanner called Primescan and chairside milling machine called the Primemill.The Primescan is an extremely faster intraoral compared the previous generation CEREC Omnicam. It is one of the fastest scanners on the market as well. Company claims that it’s easy to achieve full arch scan in under 45 seconds. Scanning is done with the working principle with Optical Structured light—Confocal microscopy with Smart Pixel sensors. The company claims that the smart pixel sensor in Primescan processes more than 1.000.000 3D points per second, producing photorealistic and highly accurate data. Primescan also has a dynamic scan depth, giving the clinician control of the scanning depth up to 20 mm, allowing accurate scans of deep margins, implants and post spaces. The Primescan is the one of the largest and heaviest scanners on the market with the weight of 457gr/525 gr depending on what scanner sleeve is used. The Primescan also has one of the largest scanner tips with the dimensions of 22.5 x 20.7 mm. This scanner doesn't require any scanning powder application. The scanner does scans in real color and scans shiny metal surfaces. The Primescan comes in one configuration-the CEREC cart. Acquisition unit has 16:9 touchscreen. The scanner has inbuilt heaters to prevent fogging on the scanner tip. As we said The CEREC system is complete in-house CAD-Cam system, the software is used to design and fabricate indirect restorations for same day applications. It can be used to design crowns, onlays/inlays, bridges, implant restorations and surgical guides. CEREC was a closed system, under the market pressure the CEREC Primescan open outwardly, users can export STL files and use this in any software of their choice but Primescan does not enable PLY or OBJ exporting. The CEREC system has yearly subscription cost in form of CEREC Club subscription but it's not mandatorily can still use the scanner without the subscription but CEREC club subscription enables clinicians to access to all the major software upgrades that are released (77) (78).

iTero Element5D-Align Technology-Cadent (Carlstadt, USA)

Figure2. 15 Itero Element 5D IOS

iTero Element 5D is latest release by the Align Technology in 2019 first being showcased in International Dental Show. Align Technology company is a leader in clear aligner orthodontics, creator of the Invisalign system. Due to that, Itero becomes scanner choice of most of the orthodontist. The scanning is done by the principle of confocal parallel imaging technology which emits red laser light and white LED light. The scanner comes in 2 configurations; a wheel stand (cart) and a scanner-only device that transforms any compatible laptop into a portable scanner. The scanner does not need any scanning powder application. The scanner is one of the largest and heaviest scanners in the market which weights 500 gr. The scanner has inbuilt heaters to prevent fogging on the scanner tip. The Element 5D is the first intraoral scanner with near-infrared imaging (NIRI) technology. NIRI is a method of spectroscopy that uses the near-infrared region of the electromagnetic spectrum (850nm). This tech enables you to scan the internal structure of a tooth in real time. This function can be used as a diagnostic aid for the detection of interproximal carious lesions above the gingiva and for monitoring the progress of such lesions without the need for radiography. TRIOS4 and Planmeca EmeraldS also have caries detection ability, but these scanners need different scan head and taking an additional scan. The Element 5D is the only scanner that simultaneously records 3D scans, intraoral 2D color images and NIRI images in one scan. Itero is just a scanner and has no CAD design software. The exporting of the scans is really simple thanks to the open nature of the Element 5D technology. The market is moving in this direction, and today almost all IOS are open systems. Remember that the Element 5D only supports STL output or exclusive file types for Invisalign. PLY and OBJ export options are absent. A color file is NOT what the STL file is. Despite the fact that the Element 5D is a color scanner, designing on a monochrome model when exporting in STL and opening in a design software (79) (80).

Table2. 1 Intraoral Scanners and Imaging Systems Used by Intraoral Scanners

IOS	Primescan	Trios 4	iTero Element 5D	Heron	EmeraldS
Manufacturer	Dentsply Sirona (York, PA, USA)	3Shape (Copenhagen, Denmark)	Align Technology (California, USA)	3disc (Herndon, VA, USA)	Planmeca (Helsinki, Finland)
Data capture principle	High-resolution Sensors and Shortwave Light with Optical High Frequency Contrast Analysis for Dynamic Deep Scan (20 mm)	Ultra-fast Optical Sectioning, confocal microcopy	Parallel Confocal Microscopy	Active stereo imaging	Projected Pattern Triangulation
Data capture mode	Video	Multiple photos	Video	Multiple photos	Video
Light Source	Blue LED	structured light	white LED and red laser	Undefined	Red, green and blue lasers
Powder	No	No	No	No	No

2.1.12. Digital Impression Techniques

2.1.12.1. Digital Impression Method in Natural Tooth Supported Prosthesis

When taking digital impressions in cases where natural teeth are the basis, isolation of the tooth and surrounding tissues is necessary after preparation. Following retraction and isolation, scanning is performed, and digitalization is achieved (81).

2.1.12.2. Digital Impression Methods in Implant Supported Prostheses

In order to obtain digital implant impressions and transfer three-dimensional implant positions into the digital system; the impression transfer parts used in the conventional impression method were replaced by the scanning parts compatible with their own implants by the companies. These scanning parts are referred to as “implant scanning abutment, scan body” in the literature. These scanning elements have different geometrical properties, such as notches and emersions which provides the information about the hex position, angle and depth of the implant. Scan bodies can be manufactured from metal, PEEK (polyetheretherketone), titanium alloy, aluminum alloy or various resins (82).

The first step of digital impression taking is placing the scan body in the mouth. This is followed by scanning the implant and adjacent tooth tissues and scanning the opposing jaw. While some companies make it possible to take an impression directly on the scan body in one step, in other companies after the scanning on the scan body is done, manufacturers advise that scan body should be removed and re scan the soft tissues around the implant and the depth of the implant are also should be recorded while the neck of the implant is visible. Following the acquisition of digital impression; the digital data in format of STL (standard tessellation language) file is sent to the laboratory, and proceeds to the production stage (82).

Manufacturer	Dentsply	DESS	Core-3D	Elos	NT-Trading	Medentika	Biohorizons	Zimmer
Implant System	Most major	Most major	Most major	Most major	Most major	Most major	Biohorizons	Zimmer
Scanner	All	All	All	All	All	All	Trios	All
CAD software	Proprietary	All major	All major	All major	All major	All major	3shape	3shape (Proprietary)
Body Material	PEEK	PEEK	PEEK	PEEK	PEEK	Ti	PEEK	PEEK
Mating Surface	Metal	PEEK	PEEK	Ti	Metal	Ti	PEEK	PEEK
Shape/Geometry	Flat cylinder with ball top	Cylinder with triangular region	Tapered flat cylinder	Cylinder with angled flat surface	Rectangular	Flat cylinder	Cone	Flat cylinder
Recommended Torque	Hand tighten	Hand tighten	Hand tighten	5 Ncm max	10 Ncm max	Hand tighten	Hand tighten	Hand tighten
Reusable	Yes, unlimited	Single use	10x for FPDs 20x single units	100x (max 2 years)	Single use	Yes, unlimited	Single use	Single use

Figure2. 16 Digital scan bodies from different manufacturers

2.1.13. Factors Affecting Digital Implant İmpression

Although several articles have compared different types of intraoral scanners in terms of accuracy and precision, the results are not consistent across studies. Therefore, the available evidence does not provide conclusive data on the best accuracy for the type of scanner. Despite the fact that all intraoral scanner systems are able to generate virtual models with adequate precision for some applications, it has been claimed that they all share the same limits (83) (84) (85) (86) (87) (88).

The factors affecting the digital implant impression can be listed as;

- Scan Body
- Intraoral Scanner and Software
- Application of scanning powder
- Scanning protocol
- Scanned Area and scanned arc length
- Image Resolution
- Optic noise
- Artifacts
- Operator Experience
- Position of the implant
- Intraoral and Patient-Related Factors (89)

2.1.13.1. Scan Body

Scan bodies are impression pieces that enable the 3D positions of the implants to be matched with the digital implant library and transferred to the digital environment by scanning with an intraoral scanner. There are intraoral scan body designed to be used in intraoral scanning and laboratory scan body types designed to be used with a laboratory scanner by placing it on a plaster model. In order to perform a high-precision surface mapping algorithm between the scan body scan and the digital implant library created by the manufacturer, the scan body surfaces must be properly visualized. By using point clouds in digital scale and this algorithm in the CAD program, the position of the digital implant analog is automatically defined in the 3D plane (hex position, angle, distance). Scan bodies available in the market and produced by different companies; They have a wide variety of features in terms of the material they are produced, size, shape, surface configurations, connection types (implant level, abutment level, etc.), scanner-software compatibility and cost (90).

Digital scan body consist of three main components. These are the apex, also known as the scan section, the middle section, known as the body, and the apical section, known as the base. The scanning section is the section where the main recording takes place and provides the transfer of data such as the position and angle of the implant. It has a flat but asymmetrical surface that allows it to be recognized by CAD software. There are one or more scan areas in this area and these areas increase the precision of the impression (69).(Figure 2.17)

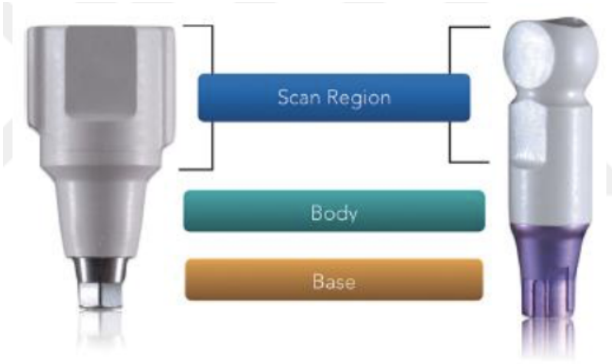


Figure2. 17 Parts of a digital scan body

Studies on digital implant impressions; revealed that scanning deep, sharp, angled, undercut, and over-configured surfaces yielded lower accuracy point clouds (91) (92).

The reusability of the scan bodies is an additional crucial factor to consider. The transfer accuracy is not affected by up to 10 consecutive uses of PEEK scan bodies, according to a study (93).

The material from which the scan body is produced is very important in terms of containing optimum surface properties. Scan bodies can be manufactured from metal, PEEK (polyetheretherketone), titanium alloy, aluminum alloy or various resins. The different production sensitivities of these materials can also affect the compatibility of the scan body with the implant or abutment (59). Their height varies from 3 to 17 mm (94).The scan bodies used are screwed or clipped to the implants (30). It has been reported that the clear fit of digital scan bodies to the original implants and analogs is important (95). It has been suggested that torqueing the scan body to the implant may lead to deformation of the base area due to excessive force, and it has been reported that this may cause vertical displacement (96). However, only a few researchers have studied the effects of the various material types of the scan body (PEEK and titanium) on the displacement caused by the torque application of the scan body (94) (96) .The manufacturer's recommended tightening torque is less than 10 Ncm for scan bodies made of PEEK material and hand tightening (59). In a study, a tightening torque of 5 Ncm instead of hand tightening torque is recommended as a recommended torque to prevent vertical displacement of the PEEK scan body (96).

In cases where there are multiple implants, it can be quite challenging for the intraoral scanner to separate these parts from each other and create an image in the correct position in the arch while scanning scan bodies with identical appearance. Intraoral scanners, especially working with the principle of combining photos, can paste different scan bodies on top of each other if they lose reference points to continue scanning (97).

2.1.13.2. Intraoral Scanner and Software

Different intraoral scanners produced by different companies; They work with different principles such as confocal microscopy, triangulation, interferometry, wave front sampling, structured light, laser and video. Due to these working principles, there can be serious differences between the image clarity they produce (59).

After the digital impression is taken, the surface configuration is performed using the point cloud obtained on the scanned object surface. This process is carried out by the algorithm in the software produced specifically for the intraoral scanner, ordering these point clouds appropriately, arranging them and combining them into a single image. Thus, a 3D model of the scanned object is obtained (56) .The high density of the point cloud enables the surface processing algorithm of the software to be performed with high precision. Thus, a 3D digital model similar to the real object surface is obtained. After the impression, some surfaces have insufficient point cloud due to insufficient scanning and the software estimates this surface by itself. The configurations performed by the software in these regions can sometimes vary considerably according to the actual volume; This results in a wide variety of distortions (59).

2.1.13.3. Application of scanning powder

Scanning powder application is mostly used for old generation intraoral scanners, modern scanners does not need any scanning powder application for scanning. Scanning powder application can be used to prevent light reflection in some special cases, such as scanning metallic objects, such as old-style scan bodies containing titanium. The application of a scanning powder may disturb the patient, and it is difficult to apply it on the object in a uniform thickness. The layers of different thicknesses is also a factor that can directly affect scanning accuracy (98) (99).

2.1.13.4. Scanning protocol

Scanning technique refers to the use of the intraoral scanner according to a particular motion to improve the accuracy of the digital model. Recent research has demonstrated the impact of the scanning path on the precision of in vivo and in vitro data obtained using confocal scanners (100). During recording, practitioners must also maintain a smooth movement that maintains a constant distance and is tooth-centered. Depending on scanners and technology (64), the camera should be held within 5 to 30 mm of the scanned surface (101).

For intraoral scanners using confocal technology, different strategies have been defined by manufacturers when the entire area is to be scanned. One of these strategies is linear motion over all occlusal-palatal surfaces and then following the buccal surfaces(Figure2.18c) .Another strategy is to perform an 'S' shaped sweeping motion on the vestibular, occlusal and lingual surfaces of each tooth(Figure2.18b) (100).

This technique limits spatial distortion by terminating image recording at the beginning point and preventing unidirectional errors, but it may not be correct for linear and undulating movements of the interproximal vestibular regions. This has prompted physicians to modify their clinical protocols in challenging areas like as interproximal space, tooth preparation, central incisors with severe curvature, and axis alteration around the canine. Moreover, lower sloping regions, such as the front mandibular region, frequently exhibit image processing issues. This constraint highlights the growing significance of intraoral scanner monitoring and software (69).

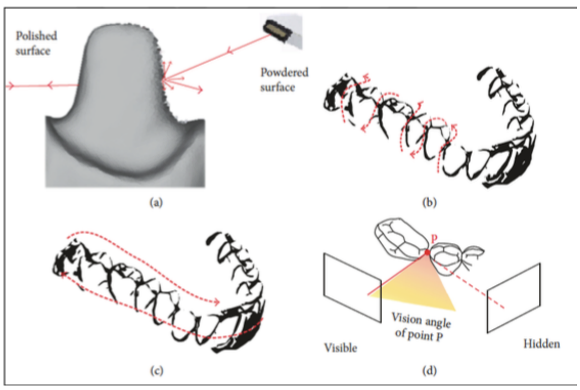


Figure2. 18 Scanning strategies. (a) The surface of the pre-prepared tooth is a reflective surface due to enamel or polishing. Powdering prevents reflection by increasing light diffusion. (b) Unidirectional scanning ('s' curve on occlusal, vestibular and lingual surfaces). (c) followed by linear movement on the buccal surface. (d) Proximate locations that are concealed if the scanning approach is ineffective.

Since the image acquisition methods of intraoral scanners vary, manufacturers recommend different scanning protocols for their scanners. However, since there are not many studies in the literature on the effect of scanning protocols on measurement accuracy, few data are available on this subject (102) (103) (104).

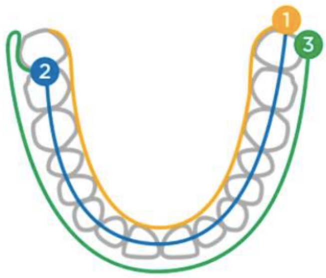


Figure2. 19 Sample scan protocol advised by manufacturer.

The amount of distortion in the anterior region is greater when the scanning direction is from the posterior to the anterior region to maintain the mouth opening. However, since the posterior regions have a larger surface area, they provide more reference points for the scanner to capture the first image. In this case, they recommended selecting the posterior regions as the first scanned area (105).

2.1.13.5. Scanned Area and scanned arc length

As the scanned arc distance increases, it becomes difficult to obtain a sufficient reference point between point clouds. In this case, it will not be possible to properly combine the images obtained separately. As a result, either optical noise and distortions occur in the resulting image, or the software cuts out some scanned regions because it cannot use the surface mapping algorithm. The majority of studies report a gradual decrease in impression accuracy as the scanning interval increases (88) (87) (106). This may be attributed to the error in the digital point meshing process. As the scanning interval increases, more point meshing errors are inevitably expected, making the scanning procedure more prone to errors (106).

The scanned arc is divided into "quadrants" according to distance or proximity from the first image. The first "quadrant" is considered the first scanned arc. The last scanned arch region is the second region and is used to define the image at a greater distance from the region where the first image was obtained. In one study, it was reported that restorations in the second zone had more distortion in the images (107).

In one study, posterior segments showed higher accuracy than anterior segments for all groups (108). For anterior regions, higher deviations were reported for both accuracy and precision parameters of the IOS devices. Teeth in the posterior region have a larger surface area and provide more reference points for the scanner to capture the first image. For this reason, posterior regions are usually preferred as the first area scanned. In this case, since the scanning direction is from posterior to anterior, the amount of distortion in the anterior region is higher. A scan of the anterior region with a small surface area yields less data than a scan of the more distal regions of the arch, and this may result in various dimensional changes (109).

It is difficult for the scanner tips to reach the interproximal and gingival areas and they are not able to image these areas at the appropriate angle. As a result, scanners may obtain less data in these areas. Therefore, digital impressions show more distortion in the gingival and interproximal regions (110).

2.1.13.6. Image Resolution

The images obtained after intraoral scanning are arranged appropriately by using meshing algorithms in the software of scanning systems. By editing the raw data, the desired images for the 3D model are obtained. However, in some cases, meshing algorithms can also cause dimensional changes by creating different surfaces on the digital image than in the original object. In order to reduce the use of these algorithms are used, intraoral scanners should be calibrated, and scans should be done in high resolution mode to get better data on the object being scanned (59) (92) .At the same time, some scanners have a high resolution mode. It is believed that scans performed using this mode will provide more accurate data (107). However, high resolution scans have a number of disadvantages. These include longer scanning time and the large size of the data, which can take up a lot of system memory (111).

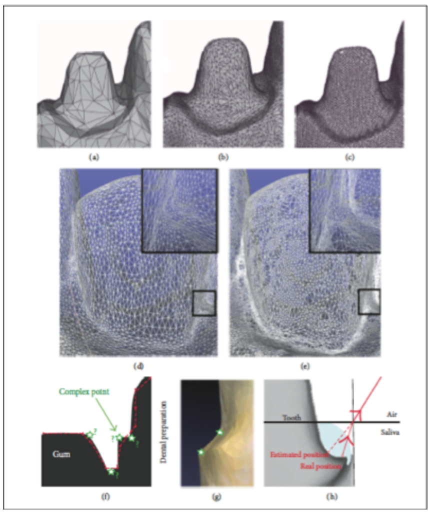


Figure2. 20 image quality. Comparison of STL files according to image density. (a) Low density. (b) Medium density. (c) High density. (d) Numerous triangles on the tooth surface. (e) Denser mesh structure in the gingival sulcus. (f) Difficult-to-scan areas present in the prepared tooth. (g) Smoothing of difficult-to-scan areas in CAD-CAM software. (h) Saliva or water layer creating errors in the margin impression and reducing the image quality.

2.1.13.7. Optic noise

When the intraoral scanner is exposed to reflected light while scanning, the images that are produced are impacted, and optical noise occurs. In order to minimize optical noise, dimensional changes that occur in surface configuration processes should be prevented by scanning in high resolution. By examining the point clouds in the 3D images obtained, optical noises can be detected, and the scan can be repeated. (112)

2.1.13.8. Artifacts

Artifact is an artificial structure or appearance created by human hands in microscopic, radiological and ultrasonographic examinations. Artifacts can occur because of; shadowing due to neighboring structures and undercut areas, moisture because of saliva or blood can reduce the quality of the data cause artifacts also optical reflection can cause artifacts as well (113).

2.1.13.9. Operator Experience

It takes time and careful consideration to become proficient with a system and integrate it into a clinic practice. Integration of the IOS system into dental procedures involves some learning. It is believed that the operator's prior familiarity with the intra oral scanner to be utilized and the clinician's knowledge of that scanning equipment are significant in the accuracy of a digital impression. Clinicians who enjoy using computers and other technology will find it simpler to implement. With different machines and scanning techniques, different results may be produced (92).

It was found that younger clinicians who grew up in the digital age and were raised with technology adapted more easily to the digital workflow in their clinical practice. It has been reported that clinicians who are older and have a certain clinical workflow find it difficult to use intraoral scanners and software (114).

2.1.13.10. Position of the implant

Since there is no material deformation from implant angulations or movement of the impression post within the impression, in theory, digital implant impressions should not be impacted. However, many studies have been conducted on this subject; some studies have shown that angulation does not affect the impression, while others have shown that angulations greater than 15°-30° can affect the impression (92) (109).

In cases where the gingival depth of the implant increases, it is thought that the impression accuracy may be affected because the amount of scan body to be visualized by the intraoral scanner will decrease. It has been reported that virtual implant positioning in the software program is significantly affected if the scan body is embedded in the gingiva. The same study reported that burying the scan body more than 1.0 mm negatively affected impression accuracy (115).

2.1.13.11. Intraoral and Patient-Related Factors

It is believed that in the intraoral environment, saliva, restrictions on mouth opening, and patient movements during the measurement may have an impact on the digital impression. The mucosa's shape may change due to jaw movements, making it challenging for the intraoral scanner to locate a reference point and continue scanning (116).

Ambient illumination is an essential factor affecting an intraoral scanner's mesh quality values or image acquisition capabilities. Depending on the selected scanner and the purpose of the digital scanning procedure, different lighting conditions are recommended to improve the outcome of digital scanning (117).

2.2. Techniques for Evaluating Accuracy of Implant Impressions

The concept of "impression accuracy"; is defined by terms of trueness and precision. Trueness refers to the digitizer's ability to make a copy of a dental arch as close to its natural shape as possible without deformation. Precision, or reproducibility, refers to the difference between images made by repeated scanning under the same conditions. Intraoral scanners must deliver consistent results across similar scans conducted at various times and must scan with great accuracy (7).

The scanned object's actual spatial geometry must be established to calculate the impression accuracy (118). In the past, different methods and devices such as 3D photogrammetry, computed tomography and microscopy were used to evaluate the accuracy, but it was stated that these methods did not provide the desired level of accurate data (119) (120). Another method is to create a virtual copy of the models obtained by impressions and compare them with a high-accuracy reference dataset (master model) through linear measurements and 3D deviation analyses with appropriate superimposing programs (7).

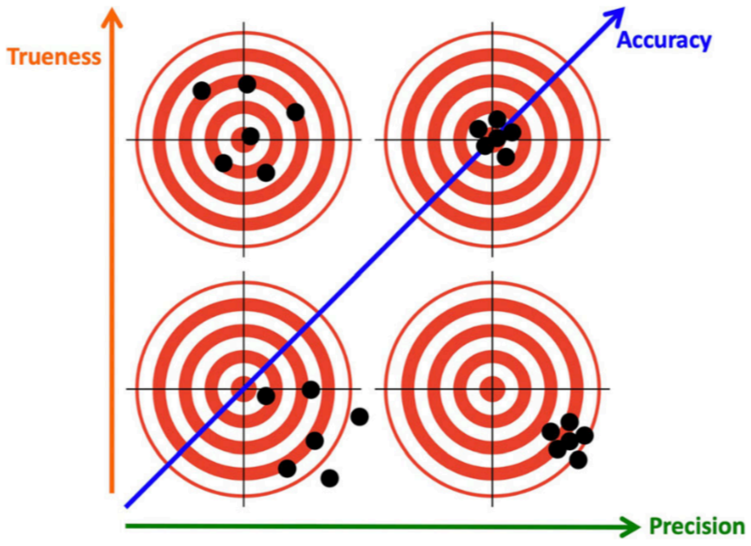


Figure2. 21 Conceptual image of the relationship between trueness and precision as defined by ISO (1994). The center of the target represents the "true value" provided by the reference data. The black dots represent test data obtained by repeated measurements. ISO, International Organization for Standardization **(118)**

2.2.1. Reference scanners

In order to compare the implant impressions with the actual implant positions, the model must be scanned with industrial optical scanners capable of scanning with high accuracy, or the coordinates of the implant must be determined in coordinate measuring devices (CMM) (121) (122).

As a result of scanning the original model with industrial optical scanners, dimensional differences may occur, even if small. Industrial optical scanners with varying scanning accuracies may distort 6 and 10 μm. (123) However, since these deviations, although higher than those of the CMM device, are clinically very low, this method is accepted in current studies in terms of measurement comparisons (88) (84).

Although the accuracy of coordinate measuring devices is 1 μm, there are some disadvantages, such as slow scanning speed and complex scanning of interproximal regions by the scanner tip due to geometric configurations. (121) (122) These disadvantages can now be overcome with scanning devices such as LineScan 2-25 fixed to the CMM. (Zeiss LineScan 2-25) was a single-line device fixed to an RDS articulating probe holder on a CMM (Contura G2 CMM). This setup moved the laser line scanner in controlled directions over the artefact. In this setup, the artefact was placed on the CMM table, and a series of three scans in the YZ projection at angles 90°, 75° and 105° were taken to cover the sides and front face of the artefact and similarly, a series of two scans a ZX projection at angles 15° and -15° to cover the top and bottom. In both instances, laser triangulation recorded data using point clouds (124).

Since these reference scanners cannot be used in the mouth due to their method of use and size, they can only be used in in vitro studies to compare impression accuracy and in vivo studies to compare reproducibility or the fit of the prosthetic parts obtained after the impression (125).

2.2.2. Evaluation of Digital Data

Various quality control software is used to investigate the accuracy of scanning systems. The concept of "reverse engineering" has been developed using quality control software in industry and engineering. Reverse engineering is based on the principle of scanning any object designed in a computer environment with high-resolution scanners after its production and comparing the images obtained with the three-dimensional information of the model designed in the computer and controlling the production quality of the part produced as a result of this process. Almost all industrial scanning devices are available with specialized software. This software allows the images of the objects scanned by the devices to be created in the virtual environment. If more than one image is obtained with the scanners, these images are combined with the software to create a single high-quality image. Quality control software performs merging and benchmarking by matching the coordinates of the points in the images in space. Each point in space has coordinates on the x, y and z axes. A single image acquired by scanners contains between 800,000 and 4,000,000 dots, depending on the scanner's efficiency. Using this particular software, during the comparison and merging processes, each imaged point is merged with the points with the same coordinates in the other image. The images are integrated in this way. At the end of design or control, the data can be exported in STL, IGES... etc. formats according to the software specification (126) (127) (123).

The evaluations can be done with a measurement comparison of the angle and distance data between the objects in the 3D model obtained after the digital impression and the data in the reference model obtained with the reference scanner. 3D comparisons are performed by determining the post-measurement displacement of the reference points determined on the model in 3 different planes. The difference in each plane can be detected individually, or it can be revealed by a 3D vector calculation. 3D vector calculations are a more practical and high-precision method to reveal dimensional differences in implant impressions (123) (16).

3D vector calculations are performed by comparing the distance and angle parameters between the reference model and the 3D obtained model to be compared. One method is superimposition, where the reference and the other 3D models are superimposed on top of each other. These STL files, which are imported into reverse engineering software, are overlaid using a best-fit algorithm, often with the help of reference point clouds, so that accuracy can be determined by revealing the dimensional difference. The level of precision can be found by detecting the dimensional difference after overlapping the images obtained by the same scanner (123) (16) (12).

However, some researchers have stated that the methods used in the superimposing technique may also cause some deviation and that this method may not give one-to-one comparison results (92) (17) (12). For this reason, some researchers have compared the reference points and lines they determined on the scan body and have determined the difference between the angles and distances between the implants and the reference model and other digital impressions

As a result, different reference scanners and comparison techniques can be used to reveal the dimensional discrepancies in the impressions. Impressions obtained with different impression techniques will produce different impression accuracy values, affecting the implant prosthesis production stage and determining the amount of fit at the prosthesis-abutment interface.

2.2.3. Passive fit and Consequences of Non- passive fit

Passive fit means that the prosthetic infrastructure does not cause force and tension on the implant, abutment and bone around the implant; It is called a fit between the prosthesis and the implant. The fit of an implant prosthesis to the abutment is directly dependent on the implant impression's accuracy and the prosthetic fabrication's precision. Therefore, the most essential and primary step in producing a passive-fitting prosthesis today is to obtain a precise impression. Passive compatibility between the prosthetic substructure and the abutment/implant is one of the most critical factors for long-term success in implant treatment. By ensuring that the entire surface of the prosthetic substructure is in proper contact with the abutment, extra loading on the abutment-implant-bone complex can be prevented (128) (129).

Teeth can move 25-100 microns axially and 56-108 microns laterally. This motion is mainly affected by existing periodontal ligaments, which explains why natural teeth are prone to migration under overload. Conversely, implants may only generate 3-5 m axial and 10-50 m lateral movement. Implants transfer their loads directly to the bone, primarily the crest (130) (131) (132).

Since implants do not have periodontal tissue, unlike teeth, in case of force on the implants, the amount of embedding in the bone is ten times less than in the teeth. Therefore, its ability to compensate for the mismatch of the prosthetic infrastructure is very low (133). Biological complications such as marginal bone loss, pain, gingival inflammation and mechanical complications such as implant/prosthesis fracture, abutment screw loosening or fracture may occur after incompatibility at the prosthesis-abutment interface. While incompatibilities in the horizontal plane cause tensile and bending stresses between the implant prosthesis and the abutment screw, on the other hand, incompatibilities in the vertical plane can cause extra load as a result of the surfaces in contact with each other and the abutment screw can loosen or break (134).

There is a wide variation in the clinically acceptable level of misfit studies that have been carried out. However, biology can tolerate some degree of misfit, though it is unclear how much. Nevertheless, to our knowledge, no longitudinal studies have specifically linked implant failures to framework misfits (135). Additionally, the perfect passive fit is practically impossible to achieve. It is still unclear what implant reconstruction misfit is clinically acceptable, even though clinicians should aim for the best fit possible (136).

According to Papaspyridakos's research on single-member implant-supported fixed prostheses (137), the maximum allowable mismatch is between 91µm and 111 µm for implant-level prostheses and 59 µm and 72 µm for abutment-level prostheses. Carr et al. (138) reported that bone resorption did not occur due to their investigation into the effects of prostheses with mismatches ranging from 38 µm to 345 µm on the marginal bone levels of patients. In a 1971 study by McLean and Von (139), it was determined that a discrepancy between the restoration and abutment between 50 µm and 100 µm was clinically tolerable. Jemt et al. (140) stated that mismatches at the abutment level should not exceed 150 µm to ensure restorations' passive fit. According to numerous studies, mismatch values below 200 µm are sufficient for long-term clinical success (141) (142). Flugge et al. (143), in a study they conducted in 2018, stated that the internal and marginal mismatch varying between 30-150 µm is sufficient to prevent mechanical and biological complications. However, the majority of these studies have produced theoretical and empirical findings; consequently, there is currently no consensus on clinically acceptable mismatch values of implant-supported prostheses that do not cause complications.

In our study, a value of 20 µ was accepted for the ideal impression limit, and the acceptable impression limit, a value of 150 µ, was accepted as stated in the American Dental Association's Specification No. 19 published on the properties of elastomeric impressions (144). Our study aimed to evaluate the trueness and precision of intraoral scanners and conventional methods to be used in implant-supported prosthetic treatments.

3. MATERIALS AND METHODS

Our study aimed to evaluate the trueness and precision of intraoral scanners and the conventional method to be used in implant-supported prosthetic treatments. Our study used a complete edentulous polyurethane lower jaw model with six implants placed both angled and parallel as a reference model. A digital reference model was created from the reference polyurethane model with the help of a CMM (Coordinate measuring machine). The polyurethane reference model was scanned ten times each with five different intraoral scanners available in the market, and digital data were created. The scans were conducted according to the manufacturer's advice. Ten conventional impressions were also taken from the reference models. The plaster models obtained from the impression were scanned with an industrial reference scanner, and data in STL format were obtained. All digital data were registered in a virtual environment with a reverse engineering program (Geomagic Control X, Geomagic, USA), and the findings were evaluated statistically. The findings were evaluated in terms of trueness and precision by comparing these data between their group and the digital reference model.

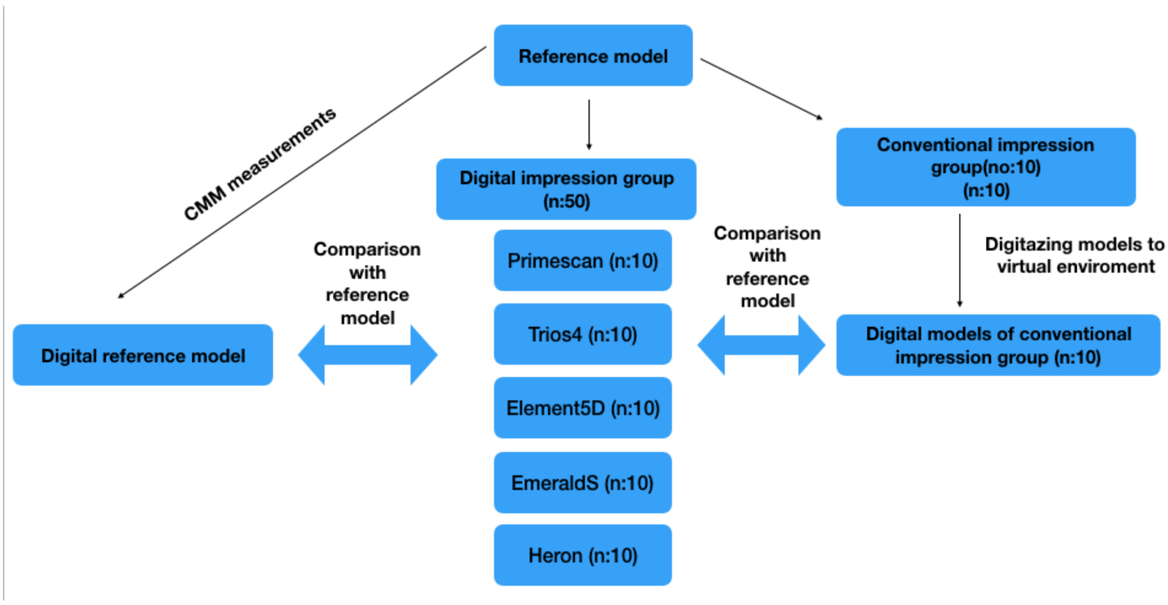


Figure3. 1 The diagram depicts the workflow of the study.

This 6-stage study was performed by the same operator:

1. Master cast fabrication
2. Obtaining the 3D Reference Model
3. Taking Digital Implant Impressions with Intraoral Scanners
4. Conventional Implant impression procedures
5. Registration of Virtual Models and Measurements
6. Statistical evaluation of the findings

3.1. Master cast fabrication

A standard full-toothed mandible model (Fransaco Study Model ANA 4, Fransaco GmbH, Tettnang, Germany) was used to create the reference models. The teeth numbered 47-46-45-44-43-43-41-31-32-33-33-34-34-35-36-37 on the model were removed using the screwdriver of the brand. A model of an edentulous mandible was duplicated with a silicon material (Elite Double; Zhermack) to fabricate the study model. duplicated reference model was poured with a polyurethane material (Alpa-Pur®, Shore A70, CHT BEZEMA R. Beitlich GMbH; Tubingen; Germany). This polyurethane-containing lower jaw model has been preferred due to its similarity to the natural bone tissue, providing easy implementation of the implantation phase with the surgical set and providing good stability for the implants. In order to obtain an implanted lower jaw model that does not reflect an ideal clinical scenario, it is planned to place six implants at different distances and angles in this polyurethane fully edentulous mandible model. In total, six implants (Straumann 4,1 mm Bone Level, Basel, Switzerland)) were placed following the implant placement protocol of the manufacturer. All implants had diameters (D) of 4,1 mm and lengths of 10 mm.

According to this planning;

- Two parallel implants were placed in the former area of the second incisors.
- Two mesial tilted implants were placed in the former region of the first premolars with an angulation of 15 degrees

- Two distally tilted implants were placed in the former region of the first molars with an angulation of 30 degrees

The points where the implants will come to the crest area of the edentulous mandible model and guidelines were drawn in the lingual area to indicate the direction of the implants with the help of a compass and surgical guides. Then, 4,1mm x 10 mm Straumann (Straumann 4,1 mm Bone Level, Basel, Switzerland) implants were placed at bone level using surgical drills at the determined locations (36, 34, 32, 42, 44, 46) guided by these lines. (Figure3.2)

Figure3. 2 Finalized version of the reference model

After all implants were placed, 6 Straumann scan bodies (CARES Mono Scan body for screw-retained abutment; Institute Straumann AG), made entirely of PEEK material and designed to fit directly into the implant (Figure3.2a), were hand screwed to the implants and made available for digital scans. All the scan bodies were new and were hand tightened according to the manufacturer's recommendations. (Figure3.3b)

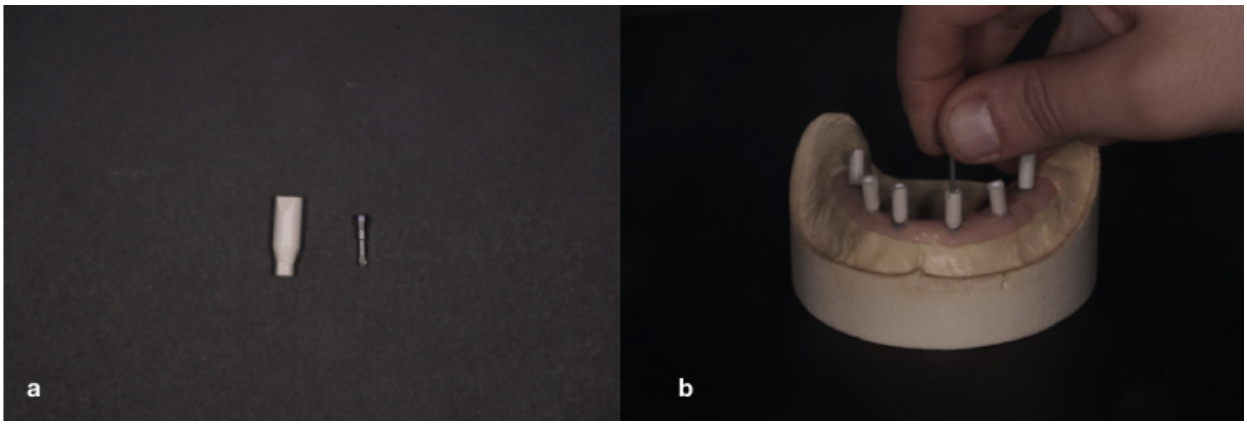


Figure3. 3 (a) CARES Mono Scan body for screw-retained abutment; Institute Straumann AG **(b)** Placement of scan bodies to model

3.2. Obtaining the 3D Reference Model

Figure3. 4 Zeiss Contura CMM- Zeiss LineScan 2-25

After the scan bodies were placed on the edentulous mandible model, the stage of obtaining a 3D reference model was started in order to compare the impression models of digital intraoral scanners and conventional impression models with the reference model. a coordinate measuring machine (CMM) (CMM Contura G2 10/16/06 RDS; Carl Zeiss Industrielle Mess Technik GmbH) was used to measure the scan body positions on the x-, y-, and z-axes by using a 0.3-mm stylus (ZEISS Vast XXT TL1 0.3 mm; Carl Zeiss Industrielle Mess Technik GmbH) at a 0.1 N tactile load The data for each scan body were condensed to the center point of the implant scan body on the x-, y-, and z-axes. Three-dimensional linear (x-, y-, and z-axes) directions of the center point displacement were calculated in millimeters. For the angular discrepancy measurements, the axis of each implant scan body of the reference implant cast was computed. Each axis had two projections, one on the x-axis (XZ angle) and the other on the y-axis (YZ angle). The manufacturer described the nominal linear accuracy of the CMM to be within 1mm on all axes.

Figure3. 5 Scanning the study model with a reference scanner

After the scan body positions were measured, the whole model was scanned by Zeiss LineScan 2-25 (Table 3.1), a single-line device fixed to an RDS articulating probe holder on a CMM (Contura G2 CMM). This setup moved the laser line scanner in controlled directions over the dental model. In this setup, the dental model was placed on the CMM table. A series of three scans in the YZ projection at angles 90°, 75° and 105° were taken to cover the sides and front face of the model and similarly, a series of two scans of a ZX projection at angles 15° and -15° to cover the top and bottom. In both instances, data recording was carried out using point clouds using laser triangulation. (Figure3.5)

Table3. 1 The technical specifications of Zeiss LineScan 2-25

Technical Specifications	Resolution (mm)	Measuring rate (points/sec)	Measuring range (mm)
LineScan 2-25	0.02	700,000	25

3.3. Taking Digital Impressions with Intraoral Scanners

A single operator with limited prior experience carried out all digital impressions in this dissertation. The approach used by Amin et al. (19) was employed in order to reduce the operator experience factor, and ten trial scans were first performed with each intra-oral scanner. This way, the operator's familiarity with the working methods of different scanners was ensured.

Figure3. 6 Reference model after placement of scan bodies

3.3.1. Scanning the model with Primescan

After the device is turned on, the 'Connect SW' program is opened. A new patient entry was created under the 'New Patient' option on the system's login screen. This process was repeated for each separate scan of the model, creating a new patient. Each separate scan data was given consecutive names as Primescan1, primescan2.-Primescan 10. After this process, 'İmpression' is selected on the main screen, and the scanner is ready for scanning. Then, since our reference model is the lower jaw, the lower jaw option was selected, and scanning was started. Following the manufacturer's recommendation, scanning was started from the occlusal surface of the scan body in the most distal region in 46. After scanning the occlusal surface of the scan body, scanning was continued from the lingual surface at an angle of 60°. In this way, the scanning continued until the scanning body was placed in the opposite arc in the area no. 36. The scanner tip was positioned parallel to the occlusal surface, and the scan was continued from the occlusal surface of scan piece 36, and the entire occlusal surface was scanned up to the region of scan piece 46. After the occlusal surface scan was finished, the scanner tip was rotated at an angle of 60°C to the vestibular surface of the scan body 46, and the scanning of the vestibular surface of all scan bodies up to the scanning piece 36 in the opposite arch was completed. At the end of each scan, the scanned surfaces were examined, and artifacts were removed using the 'Cut' option. The missing regions were scanned again, and the digital impression was completed. After ten trial scans, ten final scans were performed. Finally, the obtained scans were saved as an STL file on the computer desktop using the 'Export' option. These STL data obtained from the mandible model were taken from the computer via USB. The version of the software used during scanning is CEREC Software 5.1.

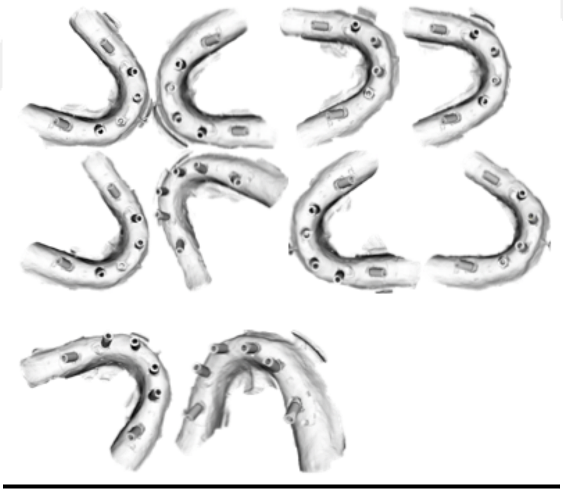


Figure3. 7 STL data of digital impressions obtained from the reference model with Primescan IOS

3.3.2. Scanning the model with Heron IOS

The Heron intraoral scanner used in our study was connected to an external computer. Patient information was entered through the HeronClinic software, and the registration process was completed. After the registration process, the "CAD/CAM" button on the main menu was selected, followed by the "New Scan and Design" and "Go to

CAD/CAM" options, and the interface was made ready for data acquisition. Finally, the "Scan" button was selected, and the scanning process was started. This process was repeated for each scan of the model, creating a new patient. Each separate scan data was given consecutive names as heron1, heron2.-heron 10. Scanning started from the scan body's occlusal surface in the most distal region in 46. After scanning the occlusal surface of the scan body, scanning was continued from the lingual surface at an angle of 60°. This way, the scanning continued until the scanning body was placed in the opposite arc in the area no. 36. The scanner tip was positioned parallel to the occlusal surface, and the scan was continued from the occlusal surface of scan piece 36. The entire occlusal surface was scanned up to the region of scan piece 46. After the occlusal surface scan was finished, the scanner tip was rotated at an angle of 60°C to the vestibular surface of the scan body 46, and the scanning of the vestibular surface of all scan bodies up to the scanning piece 36 in the opposite arch was completed. At the end of each scan, the scanned surfaces were examined, and artifacts were removed using the 'Cut' option. The missing regions were scanned again, and the digital impression was completed. After ten trial scans, ten final scans were performed. Finally, the obtained scans were saved as an STL file on the computer desktop using the 'Export' option. These STL data obtained from the mandible model were taken from the computer via USB. The software used during the scan was HeronClinic 3.2. Finally, the obtained scans were saved as an STL file on the computer desktop using the 'Export' option. These STL data obtained from the mandible model were taken from the computer via USB.

Figure3. 8 STL data of digital impressions obtained from the reference model with Heron IOS

3.3.3. Scanning the model with EmeraldS

The Planmeca EmeraldS intraoral scanner used in our study was connected to an external computer. Patient information was entered through the Romexis software, and the registration process was completed. After the registration process, the "CAD/CAM" button on the main menu was selected, followed by the "New Scan and Design" and "Go to CAD/CAM" options, and the interface was made ready for data acquisition. Finally, the "Scan" button was selected, and the scanning process was started. This process was repeated for each scan of the model, creating a new patient. Each separate scan data was given consecutive names as Emerald1, Emerald2.-Emerald 10. Scanning started from the scan body's occlusal surface in the most distal region in 46. After scanning the occlusal surface of the scan body, scanning was continued from the lingual surface at an angle of 60°. This way, the scanning continued until the scanning body was placed in the opposite arc in the area no. 36. The scanner tip was positioned parallel to the occlusal surface, and the scan was continued from the occlusal surface of scan piece 36. The entire occlusal surface was scanned up to the region of scan piece 46. After the occlusal surface scan was finished, the scanner tip was rotated at an angle of 60°C to the vestibular surface of the scan body 46, and the scanning of the vestibular surface of all scan bodies up to the scanning piece 36 in the opposite arch was completed. At the end of each scan, the scanned surfaces were examined, and artifacts were removed using the 'Cut' option. The scanning of the missing regions was performed again, and the digital impression was completed. After ten trial scans, ten final scans were performed. Finally, the obtained scans were saved as an STL file on the computer desktop using the 'Export' option. These STL data obtained from the mandible model were taken from the computer via USB. The software used during the scan was Planmeca Romexis®6.0. Finally, the obtained scans were saved as an STL file on the computer desktop using the 'Export' option. These STL data obtained from the mandible model were taken from the computer via USB.

Figure3. 9 STL data of digital impressions obtained from the reference model with EmeraldS IOS

3.3.4. Scanning the model with ITero Element 5D

After the device is turned on, the 'Connect SW' program is opened. A new patient entry was created under the 'New Patient' option on the login screen of the system. This process was repeated for each scan of the model, creating a new patient. Each separate scan data was given consecutive names as itero1, itero2.-itero10. After this process, 'Irecord' is selected on the main screen, and the scanner is ready for scanning. Then, since our reference model is the lower jaw, the lower jaw option was selected, and scanning was started. Following the manufacturer's recommendation, scanning was started from the occlusal surface of the scan body in the most distal region in 46. After scanning the occlusal surface of the scan body, scanning was continued from the lingual surface at an angle of 60°. This way, the scanning continued until the scanning body was placed in the opposite arc in the area no. 36. The scanner tip was positioned parallel to the occlusal surface, and the scan was continued from the occlusal surface of scan piece 36. The entire occlusal surface was scanned up to the region of scan piece 46. After the occlusal surface scan was finished, the scanner tip was rotated at an angle of 60°C to the vestibular surface of the scan body 46, and the scanning of the vestibular surface of all scan bodies up to the scanning piece 36 in the opposite arch was completed. At the end of each scan, the scanned surfaces were examined, and artifacts were removed using the 'Cut' option. The missing regions were scanned again, and the digital impression was completed. After ten trial scans, ten final scans were performed. Finally, the obtained scans were saved as an

STL file on the computer desktop using the 'Export' option. These STL data obtained from the mandible model were taken from the computer via USB. The version of the software used during scanning is Itero Workflow 2.0 software.

Figure3. 10 STL data of digital impressions obtained from the reference model with Itero Element5D IOS

3.3.5. Scanning the model with Trios 4

The Trios4 device used in our study was operated with an external computer connection using the manufacturer's interface program. When logging in to the main screen, the 'patient' option was selected, new patient information was filled in, and a record was created for each scan. Each separate scan data was given consecutive names as Trios1, Trios2.-Trios 10. After choosing the "new case" option, the software opens a window that asks which treatment option should be used in the new case. Trios (Copenhagen, Denmark) stated that it is essential that the software to figure out the type of restoration to be done because of the different algorithms and levels of sensitivity involved. For the restoration type, the implant-supported prosthesis option is selected. The jaw to be scanned was chosen, and the message "Scanner ready" was shown before the scan began. The scans were performed in a pattern in accordance with the 'User Instructions' published by Trios. Starting from the most distal region, the occlusal surfaces of the scan bodies 46, 44, 42, 32, 34 and 36 were first scanned. Afterward, the vestibular surface of the scan bodies 36, 34, 32, 42, 44 and 46 were scanned by inverting the scanner tip and turning the vestibular surface at an angle of 45°C. Then, the scanner tip was turned over and rotated 45°C to the lingual surface. All lingual surfaces were scanned up to the scan body at the end of the opposite arch. At the end of each scan, the scanned surfaces were examined, and artifacts were removed using the 'Cut' option. The missing regions were scanned again, and the digital impression was completed. After ten trial scans, ten final scans were performed. The software used during the scan was 3shape TRIOS 20.1.3. Finally, the obtained scans were saved as an STL file on the computer desktop using the 'Export' option. These STL data obtained from the mandible model were taken from the computer via USB.

Figure3. 11 STL data of digital impressions obtained from the reference model with Trios4 IOS

3.4. Conventional Implant impression procedures

Firstly, 6 PEEK scan-body on the reference model were removed to take conventional implant impressions. 6 open tray impression copings (Straumann, RC open tray impression post, Switzerland) were attached to the implants by hand force. (Figure3.12)

Figure3. 12 Straumann, RC open tray impression post, Switzerland

A prefabricated acrylic resin bar (Prefabricated Resin Bar, Bego, Germany) was used to splint the impression coping, where the prefabricated bar was cut according to the distance between the impression coping with a diamond disc (Diamond Disc, Mend Tech Inc, USA), then was attached in each side using cold acrylic resin. Application of the cold acrylic resin was done in an incremental manner, where a fine brush was dipped in the liquid of the acrylic resin to make it wet on the top and then the brush was slightly dipped into the powder in a very delicate way to get some powder on the top of the brush which will start to polymerize in few seconds. The resin was applied on the side of the prefabricated resin bar to join it with the impression coping, after finishing this step the model was left for 24 hours. before making the impression, ensure that most of the resin's polymerization shrinkage is finished. These procedures were repeated for each model before each impression application. (Figure3.13)

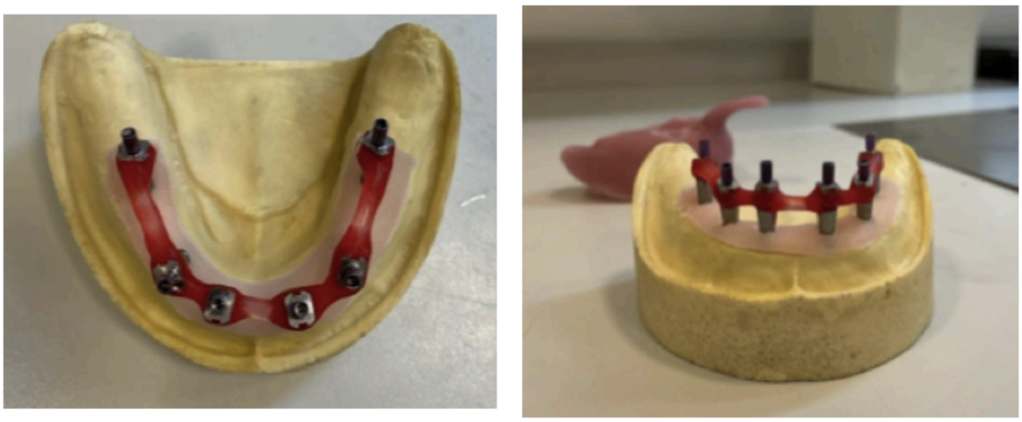


Figure3. 13 Splinting of conventional impression copings

After the impression posts were placed in the reference model, the stage of preparing the individual custom tray was started for each model. In order to provide sufficient and homogeneous space to the polyvinyl siloxane impression material to be used in the conventional impressions, 3 mm thick wax was applied to the model. A light-cured base plate (Cavex Dental Baseplates - Cavex, Netherlands) was placed on the model. Care was taken to ensure that the borders of the treys were in line with the sulcus and that a window was made in the areas where the impression transfer pieces were positioned. After light polymerization of the prepared acrylic resin trays, the areas corresponding to the impression posts on the custom trays were drilled and made suitable for the open tray impression procedure, and ten individual impression trays were obtained after polishing and leveling. (Figure3.14)

Figure3. 14 Preparation of custom impression trays

Normal set Elite HD+ putty soft and Elite HD+ light body (Zhermack Spa, Italy) polyvinyl siloxane was used as impression materials for conventional implant impressions. Kerr polyvinyl siloxane tray adhesive (KaVo Dental GmbH, Bismarckring, Germany) was applied to the individual tray before each impression and waited for 10 minutes. Then, while one clinician applied the viscous light body to the impression posts in the study model with the help of a dispenser, the other clinician mixed the base and catalyst of the putty-like PVS in a 1:1 ratio with bare hands until homogeneous. The mixed putty was placed in the tray and finally, the tray was placed on the working model for a one-step impression with the light body applied lightly on the putty. The impressions were made in a controlled-temperature environment (25°C with a relative humidity of 50%) Bilateral finger pressure was applied for the duration of the setup time to standardize the seating load for each impression. The impression material may be set in accordance with the manufacturer's recommendations. Then, the PVS on the open impression posts was cleaned a little bit in order to reach the screw parts easily and the impression material was allowed to harden. Once all of the impression material had been set, the imprint coping was carefully unscrewed, and the tray was then carefully withdrawn from the model in an anterior-superior direction (Figure3.15). The implant analogs were then attached to the copings and screwed in accordance with the manufacturer's instructions.

Figure3. 15 Conventional implant impression

Prior verification was done for all ten impressions to ensure no discrepancies, air bubbles, uncorrected sets, loose impression coping, or other errors. Before pouring, each impression was boxed with wax to make a 3 cm base, and any excess was trimmed for any excess material with the tray margin. A double-mixing technique was used to lessen the effect of the stone getting bigger or smaller. After the trimming, Type - 4 dental stone (Type Four Dental Stone, Dentona, Germany) was poured into the obtained silicone matrix. For this purpose, 20 ml of distilled water was added to 100 g of Type-4 dental stone powder. After the first 15 seconds of mixing was done by hand, it was continued for 45 seconds in a vacuum plaster mixing device (Smartmix Smart-Mix, AmanngirrBach Gmbh, Pforzheim, Germany). As advised by the manufacturer, the casts were given 120 minutes to set before the impressions were detached from the casts. To separate the splinted-direct technique models, the screws were loosened. The impression copings needed to be unscrewed from the implant analogs and followed by trimming the edges for the models and labeling to prepare for the digitalization of conventional models. The same operator prepared all ten models in all laboratory procedures. Before scanning, all the models were kept at room temperature for 24 hours.

Figure3. 16 Placement of scan bodies on conventional plaster model

Figure3. 173Shape 3E Laboratory scanner used in this study

In order to make comparative measurements, six scan bodies (CARES Mono Scan body for screw-retained abutment; Institute Straumann AG) were again placed on these dental stone models to be digitally scanned in the laboratory scanner. Then, 3D data were obtained by placing each model in a suitable position on the digital laboratory scanner (3Shape 3E Lab Scanner, Copenhagen, Denmark) (Figure 3.17). Following the digitization of the ten dental stone models made from the ten open tray impressions with a lab scanner, conventional impression models were also obtained in STL format. (Figure3.16)

Figure3. 18 STL data of conventional impressions obtained from the reference model

3.5. Registration of Virtual Models and Measurements

The digital data obtained as a result of scanning the reference model with a CMM scanner and all the digital impressions obtained from all intraoral scanners and conventional models scanned by lab scanner were opened in the Geomagic Control X (Geomagic, USA) software. Since the data is in stl. format, no file conversion was required. Then, in order to perform the measurements in the Geomagic Control X program, the first step was to determine the reference points on the scan body.

As can be seen in the Figure3.10, the top surface of the scan body will form the plane 3 points were identified and a reference plane was created. Using this plane, 2 separate reference planes were created at a distance of 2.5 mm and 5 mm, from which the circles necessary to determine the reference axes of the cylinders in the scanning parts were drawn. (Figure3.19)

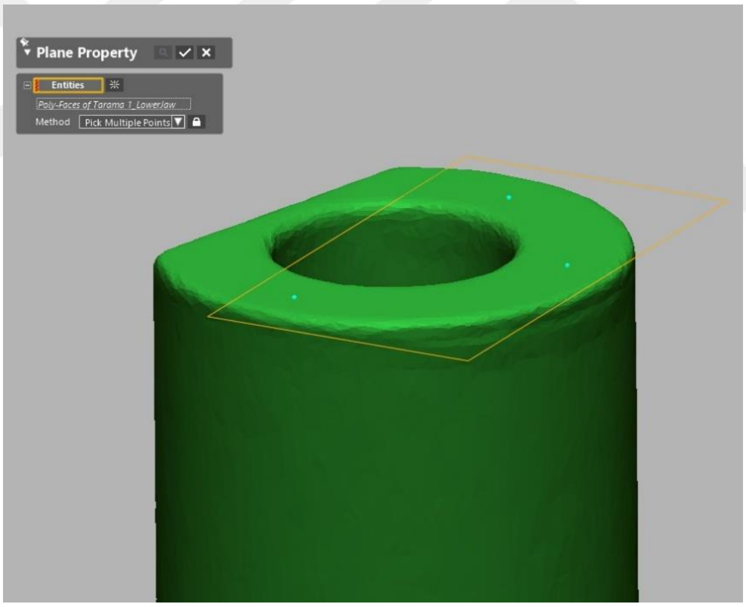


Figure3. 19 Determination of the reference plane

Then, new circles were drawn on the mesh sketch curves in the defined planes and the center point of the cross section was obtained. It is important for the accuracy of the process that the pink colored circles in the mesh sketch are completely covered while drawing the circles. In the next step, the "point" command was used to define the points that give the coordinates of the circle centers to be used in 3D deviation measurements. (Figure3.20)

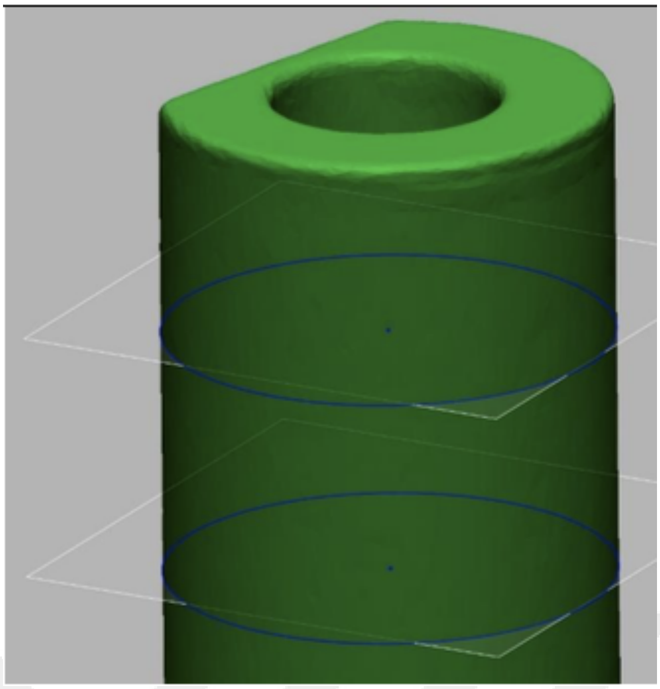


Figure3. 20 Determination of the implant center point

According to our model scenario, we placed Two parallel implants were placed in the former area of the second incisors(33,43), Two mesial tilted implants were placed in the former region of the first premolars(34,44) with an angulation of 15 degrees and Two distally tilted implants were placed in the former region of the first molars with an angulation of 30 degrees(36,46) . In order to calculate the deviation locations of the impression groups, implants, which were named with numbers such as 46, 44, 42, 32, 34, 36 before the statistical analysis, were named with letters at this stage and They were grouped according to their angle and location similarities. (Figure3.21)

The implant named as A is the implant in the region number 46,

The implant labeled B is the implant in the number 44 area,

The implant labeled C is the implant in the area number 43,

The implant labeled D is the implant in the area number 33,

The implant labeled E is the implant in the number 34 area, The implant labeled F represents the implant in the number 36 region. (Figure3.21)

AF Group-Implants placed in molars with 30 degrees

CD group- Implants placed in premolars with 15 degrees

BE group-Implants placed parallel in incisors. (Figure3.21)

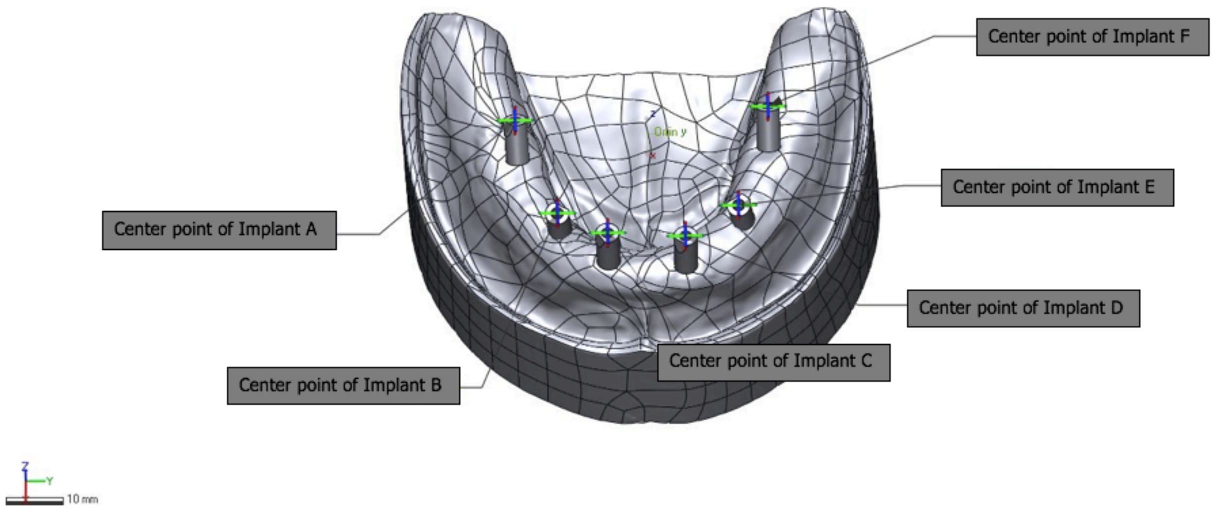


Figure3. 21 Labels of implant center points

In addition, as a side analysis, the Geomagic program determined two specific reference points on the scan bodies on each implant from three distinct perspectives, buccal, lingual, and occlusal, and evaluated the degree of 3D deviation. (Figure3.22) (Figure3.23) (Figure 3.24)

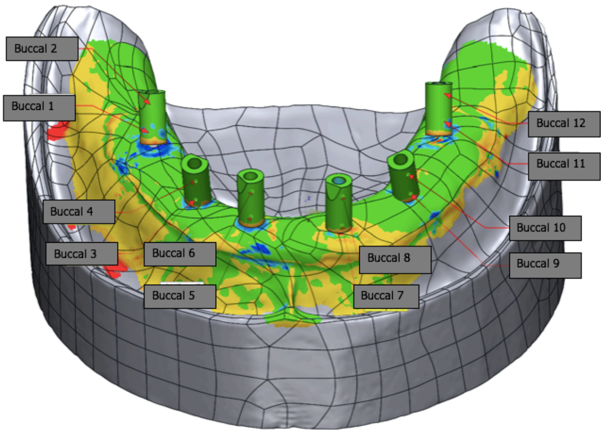


Figure3. 22 Reference points on implants in Buccal view

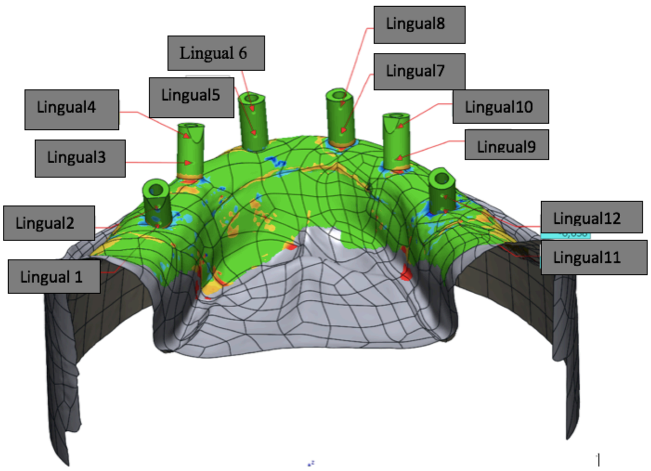


Figure3. 23 Reference points on implants in Lingual view

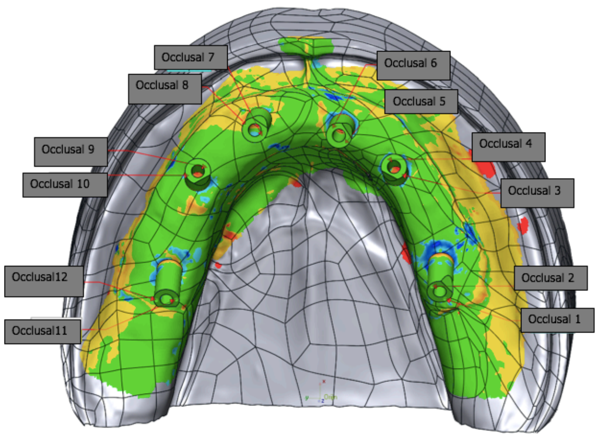


Figure3. 24 Reference points on implants in occlusal view

The data obtained from the reference model was aligned one by one with intraoral scanner models and conventional models, first with the initial alignment option and then with the best-fit alignment option. Best fit registration was performed such that the scan body head region data 'best' matched the reference data and the experiment group data. After registration, the color map (3D Deviation - Color Map) feature of Geomagic Control X software was used to generate color maps compatible with the amount of 3D deviation produced for each model. The software performed three-dimensional deviation measurements between implant center points and selected points on the scan body. (Figure3.25)

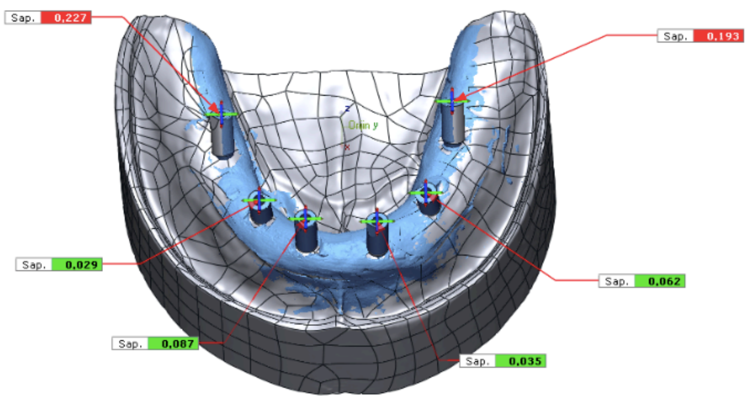


Figure3. 25 Rms values of 3D deviation of implant Canter points

Geomagic Control X software provides the root mean square (RMS) value of the square root of the mean deviation in determining the amount of 3D deviation. The amount of deviation in all planes is calculated in 3D and converted into a mathematical value. On the comparison program, mm was chosen as the unit parameter. A color map was created for all samples, the amount of deviation at the selected points was reported and the RMS values obtained were recorded and statistically evaluated (Figure 3.26). The following formula was applied in the calculation;

$$RMS=\frac{1}{\sqrt{n}}\cdot\sqrt{\sum_{i=1}^{n}(X_{1,i}-X_{2,i})^2}$$

X1 is the coordinate of the corresponding 'i' point in the reference model, X2 is the coordinate of the corresponding 'i' point in the experimental model, and n is the total number of points in the data. (145) (146)

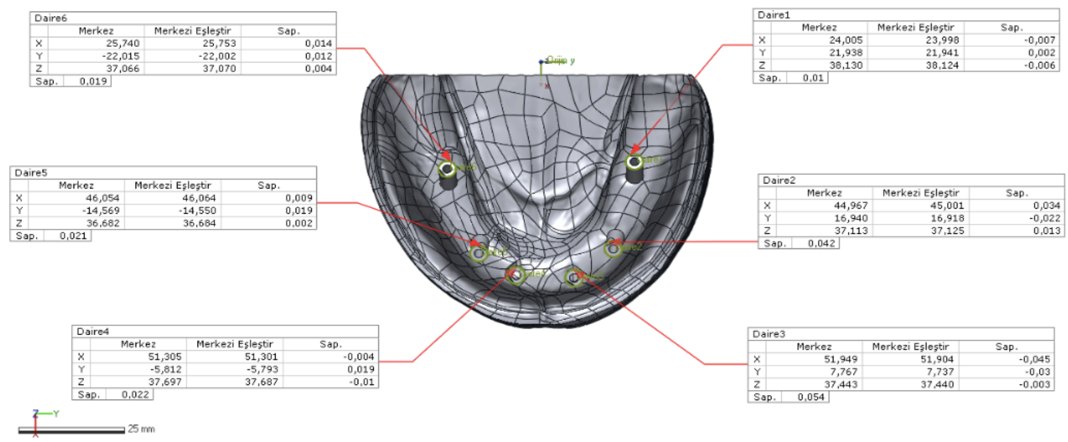


Figure3. 26 3D deviations of center of the implants in X, Y, Z axes

The color map displays the available colors according to a certain scale (Figure3.20). Respectively, areas colored in green indicate an ideal fit, while areas colored in shades of red and blue indicate negative and positive deviations. The darkest blue areas indicate the greatest deviation and positive value; that is, the areas in the test sample where the impression is wider than the reference model, while the darkest red areas show the greatest deviation and have a negative value; that is, it shows areas where the impression in the test sample is narrower than the reference model. From these expressions, the contraction and expansion of the conventional impression can be understood, while it is more accurate to specify "wide" and "narrow" for digital impressions. (Figure3.27)

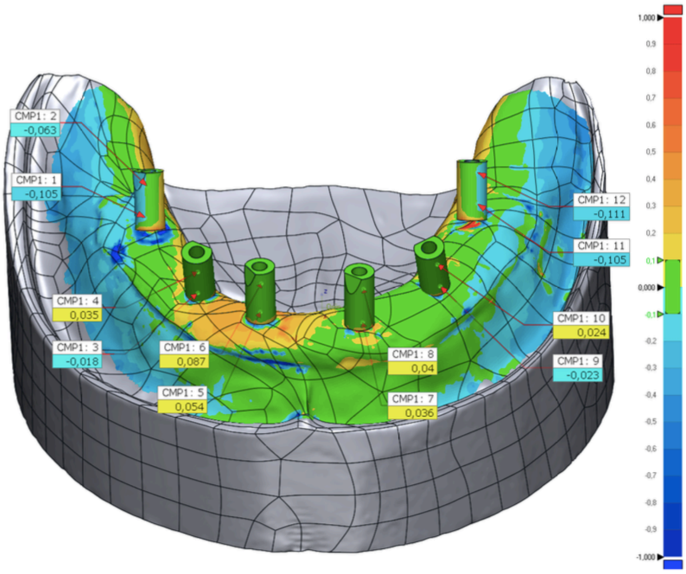


Figure3. 27 Geomagic Control X software's color map feature

The user determines the values in the color scale of the map. In our study, the determination of ideal and acceptable deviations in impressions was based on the American Dental Association's Specification No. 19, published on the properties of elastomeric impressions. (144) According to these specifications, the value indicated in green and considered ideal is ±20 microns, while the value coded in dark blue and dark red, ±150 microns, is considered clinically acceptable.

3.5.1. Evaluating the Precision of Impression Groups

To determine the Precision levels of the impression methods, the average of the deviation data of 10 scans of each impression group(n:60) and the average of these 10 impression groups was calculated to determine the overall mean value of the impression group (n:6). Then, the difference between the overall mean values of the impression groups and the ten impressions was calculated, and the deviation from the mean value of that scanner was determined for each impression group. The absolute value statistics of these deviations were also calculated to determine the extent to which the impression groups were able to perform consistent impressions obtained at different times; in other words, their repeatability level was tried to be determined.

3.6. STATISTICAL ANALYSES

Statistical analyses performed using the IBM SPSS software version 28. The variables were investigated using visual (histograms) and analytical methods (Kolmogorov-Smirnov/Shapiro-Wilk's test) to determine whether or not they are normally distributed. Descriptive analyses were presented using medians, interquartile range (IQR), minimum and maximum values for non-normally distributed variables. As the variables of the groups were not normally distributed the Kruskal-Wallis tests were conducted to compare these parameters and the ordinal variables among the impression methods. A Mann-Whitney U test was performed to test the significance of pairwise differences using Bonferroni correction adjust for multiple comparisons. An overall %5 type-1 error level was used to infer statistical significance.

4. RESULTS

In our study, the average amount of surface deviation was obtained as a result of the superimposing of the reference data and the data of the experimental groups taken, and these values were evaluated statistically. The parameters considered in the evaluation phase are trueness, where the 3-dimensional deviation in the impression is determined; the Root Mean Square (RMS) value is used; and precision, where the consistency of the experimental groups is evaluated. On the comparison program, mm was chosen as the unit parameter. A lower deviation value in 'mm' means higher in trueness.

4.1. Deviation of center point of implants

Table4. 1 Root mean square deviation values of center points of implants for impression groups (mm)

IOS	Nx*	Median	IQR	min	max	Skewness
Primescan	**60**	0,036	0,037	0,008	0,27	3,64
3Shape	**60**	0,048	0,042	0,007	0,234	1,76
İtero	**60**	0,034	0,031	0,012	0,128	1,482
Planmeca	**60**	0,075	0,097	0,018	0,241	0,727
Heron	**60**	0,11	0,080	0,034	0,343	1,063
Conventional	**60**	0,07	0,06	0,017	0,27	1,711

As a result of the measurements, the median deviation of Primescan was 0.036mm. (IQR=0.037, min=0.00, max=0.27mm)

The median deviation of Trios 4 -3Shape was 0,048mm.

(IQR=0,042, min=0,007mm, max=0,234mm)

The median deviation of Heron ios-3disc was 0,11mm.

(IQR=0,080, min= 0,034mm, max=0,343mm)

The median deviation of Emerald S-Planmeca was 0,075mm.

(IQR=0,097, min= 0,018mm, max=0,241mm)

The median deviation of Itero Element5D-Align Technology-Cadent was 0,034mm.

(IQR=0,06, min=0,017mm, max=0,27mm)

The median deviation of the conventional impression group was 0,07mm

(IQR=0,06, min=0,017mm, max=0,27mm)

The median deviation was lowest in Itero Element5D-Align Technology-Cadent (0.0034mm IQR=0,06), Highest median deviation found in Heron ios-3disc (0,11mm, IQR=0,080) (Table4.1)

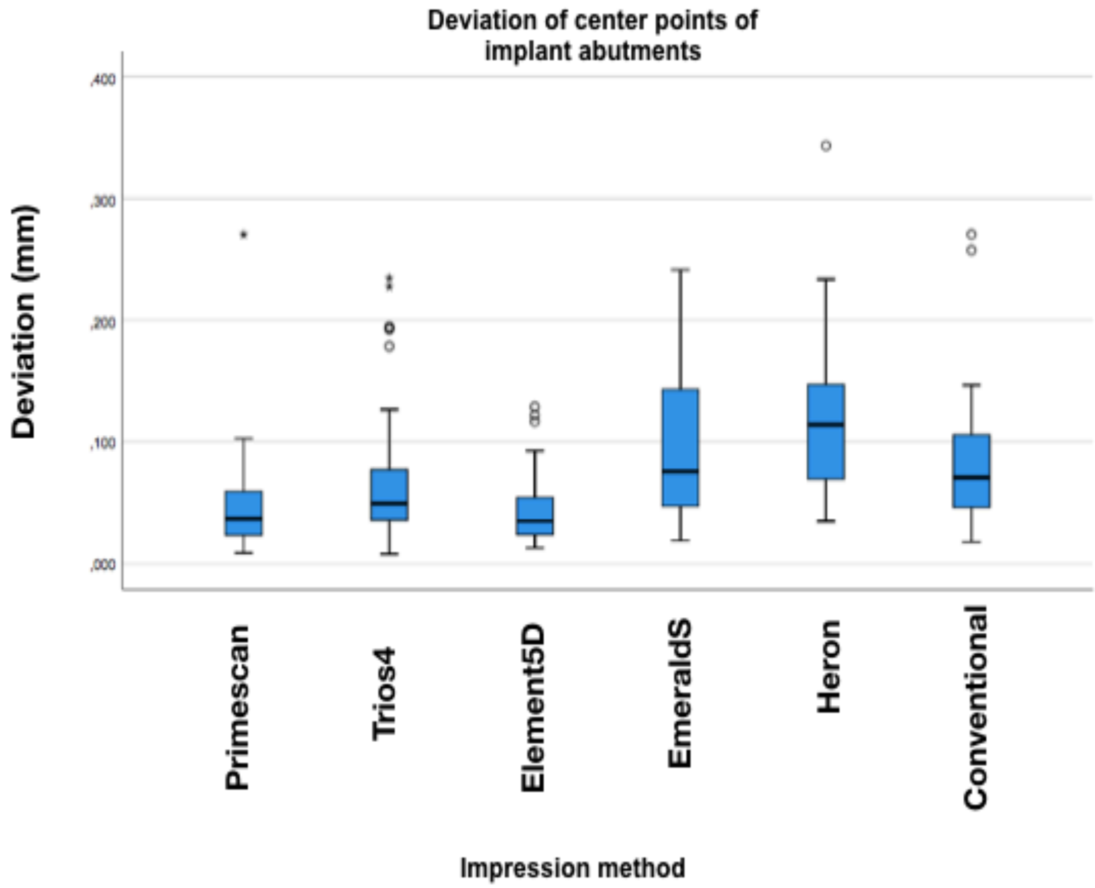


Figure4. 1 Boxplots representing the 3D deviation of implant center points for each impression group in the overall analysis.

The median deviation of the devices:

Itero Element5D-Align Technology-Cadent (0.034mm, IQR=0,06) < **Primescan** (0.036mm, IQR=0.037) < **Trios 4 -3Shape** (0,048mm, IQR=0,042) < **Conventional impression group** (0,07mm, IQR=0,06) < **Emerald S-Planmeca** (0,075mm, IQR=0,097) < **Heron ios-3disc** (0,11mm, IQR=0,080). (Table4.1)

Table4. 2 Man Whitney U test results for pairwise comparison of impression methods

Pairwise Comparisons of impression methods

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
itero-Primescan	6,083	18,999	,320	,749	1,000
itero-3shape	49,525	18,999	2,607	,009	,137
itero-Conventional	-94,033	18,999	-4,949	<,001	,000
itero-Planmeca	-113,142	18,999	-5,955	<,001	,000
itero-Heron	-153,267	18,999	-8,067	<,001	,000
Primescan-3shape	-43,442	18,999	-2,287	,022	,333
Primescan-Conventional	-87,950	18,999	-4,629	<,001	,000
Primescan-Planmeca	-107,058	18,999	-5,635	<,001	,000
Primescan-Heron	-147,183	18,999	-7,747	<,001	,000
3shape-Conventional	-44,508	18,999	-2,343	,019	,287
3shape-Planmeca	-63,617	18,999	-3,348	<,001	,012
3shape-Heron	-103,742	18,999	-5,460	<,001	,000
Conventional-Planmeca	19,108	18,999	1,006	,315	1,000
Conventional-Heron	59,233	18,999	3,118	,002	,027
Planmeca-Heron	-40,125	18,999	-2,112	,035	,520

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is ,050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table4. 3 Simplification of results of Man Whitney U test

P value	Primescan	3shape	Conventional	Planmeca	İtero	Heron
Primescan		0.33	<0.01	<0.01	1.00	<0.01
3shape			0,287	0.01	0,137	<0.01
Conventional				1.00	<0.01	0.02
Planmeca					<0.01	0.52
İtero						<0.01
Heron						

*A Man Whitney U Test P<0.05
*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

The Kruskal-Wallis test revealed significant differences in trueness values among the six groups tested (P<0,05). A Man Whitney U test was performed to determine between which paired groups the significant difference originated, and the findings are presented in Table 4.2

The median deviation values of the Primescan group were significantly lower than those of the Emerald S-Planmeca group, Heron ios-3disc group and conventional impression group. (P<0,05)

The Trios 4 -3Shape group's median deviation values were significantly lower than those of the Emerald S-Planmeca group and Heron ios-3disc group. (P<0,05)

The median deviation values of the Itero Element5D-Align Technology-Cadent group were significantly lower than those of the Emerald S-Planmeca group, Heron ios-3disc group and conventional impression group. (P<0,05)

The median deviation values of the conventional impression group were significantly lower than those of the Heron ios-3disc group. (P<0,05)

There were no significant differences in trueness values among Trios 4 -3Shape group, iTero Element5D-Align Technology-Cadent group and Primescan group. (P>0,05)

There were no significant differences in trueness values among Trios 4 -3Shape and conventional impression groups. (P>0,05)

There were no significant differences in trueness values among the Emerald S-Planmeca and conventional impression groups. (P>0,05)

There were no significant differences in trueness values among the Emerald S-Planmeca group and Heron ios-3disc group. (P>0,05) (Table4.3)

4.2. Deviation of Points in Buccal view

Table4. 4 Root mean square deviation values of selected buccal points of implants for impression groups (mm)

IOS	Nx	Median	IQR	Min	Max	Skewness
Primescan	120	0,032	0,026	0	0,094	0,581
3Shape	120	0,0315	0,031	0,001	0,145	1,496
İtero	120	0,023	0,028	0	0,129	1,770
Planmeca	120	0,051	0,071	0	0,16	0,482
Heron	120	0,064	0,055	0	0,181	0,456
Conventional	120	0,070	0,070	0,004	0,235	0,845

As a result of the measurements, the median deviation of Primescan was 0.032mm.
(IQR=0.026, min=0mm, max=0.94mm)
The median deviation of Trios 4 -3Shape was 0,0315mm.
(IQR=0,031, min=0,001mm, max=0,145mm)
The median deviation of Heron ios-3disc was 0,064mm.
(IQR=0,055, min= 0mm, max=0,181mm)
The median deviation of Emerald S-Planmeca was 0,051mm.
(IQR=0,071, min= 0mmm, max=0,16mm)
The median deviation of Itero Element5D-Align Technology-Cadent was 0,023mm.
(IQR=0,028, min=0mm, max=0,129mm)
The median deviation of the conventional impression group was 0,07mm.
(IQR=0,07, min=0,04mm, max=0,235mm)

The median deviation was lowest in Itero Element5D-Align Technology-Cadent (0.023mm, IQR=0,028). Highest median deviation was found in the conventional impression group (0,070mm, IQR=0,070). (Table 1.4)

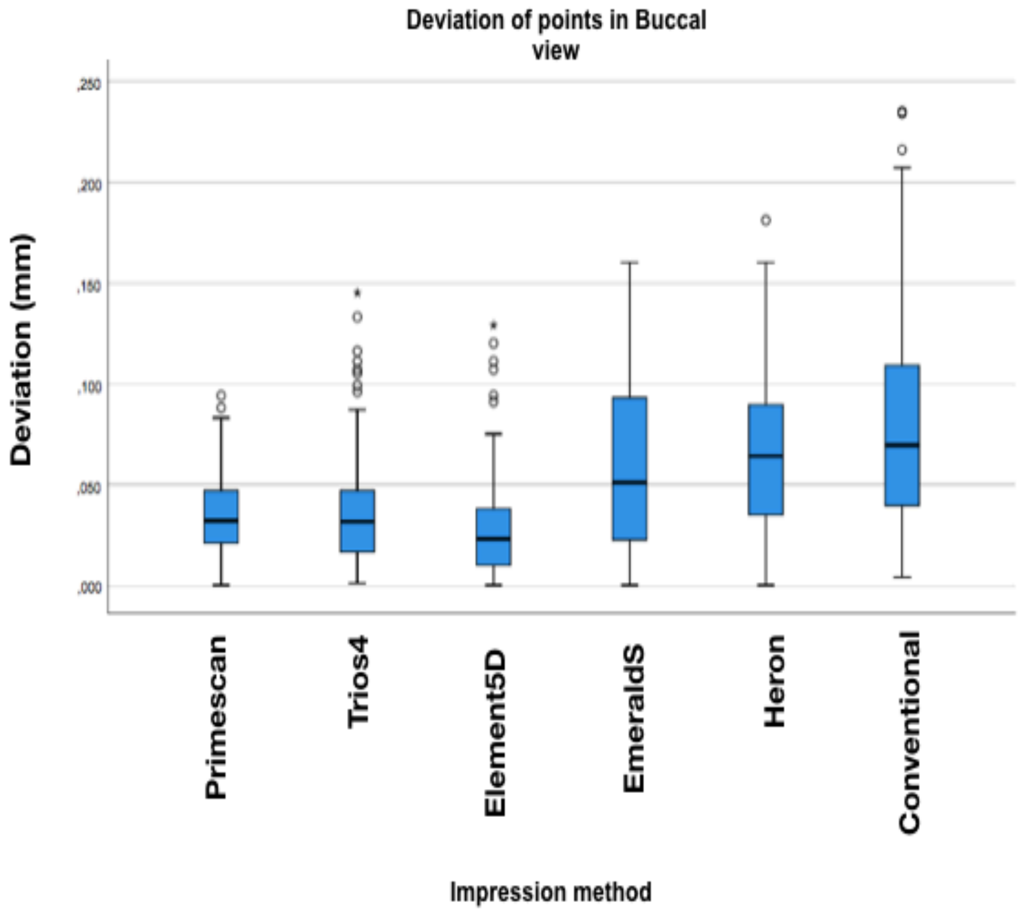


Figure4. 2 Boxplots representing the deviation of selected points in Buccal view for each impression group in the overall analysis.

The median deviation of the devices:

Itero Element5D-Align Technology-Cadent (0.023mm, IQR=0,028) < **Trios 4 - 3Shape** (0,0315mm, IQR=0,031) < **Primescan** (0.032mm, IQR=0.026) < **Emerald S-Planmeca** (0,051mm, IQR=0,071) < **Heron ios-3disc** (0,064mm, IQR=0,055)< **Conventional impression group** (0,07mm, IQR=0,07) (Table 2.4)

Table4. 5 Man Whitney U test results for pairwise comparison of impression methods

Pairwise Comparisons of impression methods

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
itero-3shape	56,467	26,850	2,103	,035	,532
itero-Primescan	59,400	26,850	2,212	,027	,404
itero-Planmeca	-160,358	26,850	-5,972	<,001	,000
itero-Heron	-194,921	26,850	-7,260	<,001	,000
itero-Conventional	-247,404	26,850	-9,214	,000	,000
3shape-Primescan	2,933	26,850	,109	,913	1,000
3shape-Planmeca	-103,892	26,850	-3,869	<,001	,002
3shape-Heron	-138,454	26,850	-5,157	<,001	,000
3shape-Conventional	-190,937	26,850	-7,111	<,001	,000
Primescan-Planmeca	-100,958	26,850	-3,760	<,001	,003
Primescan-Heron	-135,521	26,850	-5,047	<,001	,000
Primescan-Conventional	-188,004	26,850	-7,002	<,001	,000
Planmeca-Heron	-34,562	26,850	-1,287	,198	1,000
Planmeca-Conventional	-87,046	26,850	-3,242	,001	,018
Heron-Conventional	-52,483	26,850	-1,955	,051	,759

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is ,050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table4. 6 Simplification of results of Man Whitney U test

P value	Primescan	3shape	Conventional	Planmeca	İtero	Heron
Primescan		1.00	<0.01	0,003	0,404	<0.01
3shape			<0.01	0,002	0,532	<0.01
Conventional				0,018	<0.01	0,759
Planmeca					<0.01	1.00
İtero						<0.01
Heron						

**A Man Whitney Test P<0.05
*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

The Kruskal-Wallis test revealed significant differences in trueness values among the six groups tested (P<0.05). A Man Whitney U test was performed to determine between which paired groups the significant difference originated, and the findings are presented in Table 4.5

The median deviation values of the Primescan group were significantly lower than those of the Emerald S-Planmeca group, Heron ios-3disc group and conventional impression group. (P<0,05)

The Trios 4 -3Shape group's median deviation values were significantly lower than those of the Emerald S-Planmeca group and Heron ios-3disc group. (P<0,05)

The median deviation values of the Itero Element5D-Align Technology-Cadent group were significantly lower than those of the Emerald S-Planmeca group, Heron ios-3disc group and conventional impression group. (P<0,05)

The median deviation values of the Emerald S-Planmeca group were found to be significantly lower than the deviation values of the conventional impression group. (P<0,05)

There were no significant differences in trueness values among Trios 4 -3Shape group, Itero Element5D-Align Technology-Cadent group and Primescan group. (P>0,05)

There were no significant differences in trueness values among the Emerald S-Planmeca group and Heron ios-3disc group. (P>0,05)

There were no significant differences in trueness values among the conventional impression group and the Heron ios-3disc group. (P>0,05) (Table4.6)

4.3. Deviation of points in lingual view

Table4. 7 Root mean square deviation values of selected lingual points of implants for impression groups (mm)

IOS	Nx	Median	IQR	Min	Max	Skewness
Primescan	120	0,020	0,020	0	0,111	1,670
3Shape	120	0,031	0,032	0,001	0,089	0,588
İtero	120	0,019	0,035	0	0,161	1,654
Planmeca	120	0,048	0,058	0,001	0,183	0,791
Heron	120	0,046	0,054	0	0,214	1,096
Conventional	120	0,037	0,064	0	0,168	0,917

As a result of the measurements, the median deviation of Primescan was 0.020mm.
(IQR=0.020, min=0mm, max=0.111mm)
The median deviation of Trios 4 -3Shape was 0,031mm.
(IQR=0,032, min=0,001mm, max=0,089mm)
The median deviation of Heron ios-3disc was 0,046mm.
(IQR=0,054, min= 0mm, max=0,214mm)
The median deviation of Emerald S-Planmeca was 0,048mm.
(IQR=0,058, min= 001mm, max=0,183mm)
The median deviation of Itero Element5D-Align Technology-Cadent was 0,019mm.
(IQR=0,035, min=0mm, max=0,161mm)
The median deviation of conventional impression group was 0,037mm.
(IQR=0,064, min=0mm max=0,168mm)

The median deviation was lowest in Itero Element5D-Align Technology-Cadent (0.019mm, IQR=0,035), Highest median deviation was found in Emerald S-Planmeca (0,048mm, IQR=0,058). (Table 4.7)

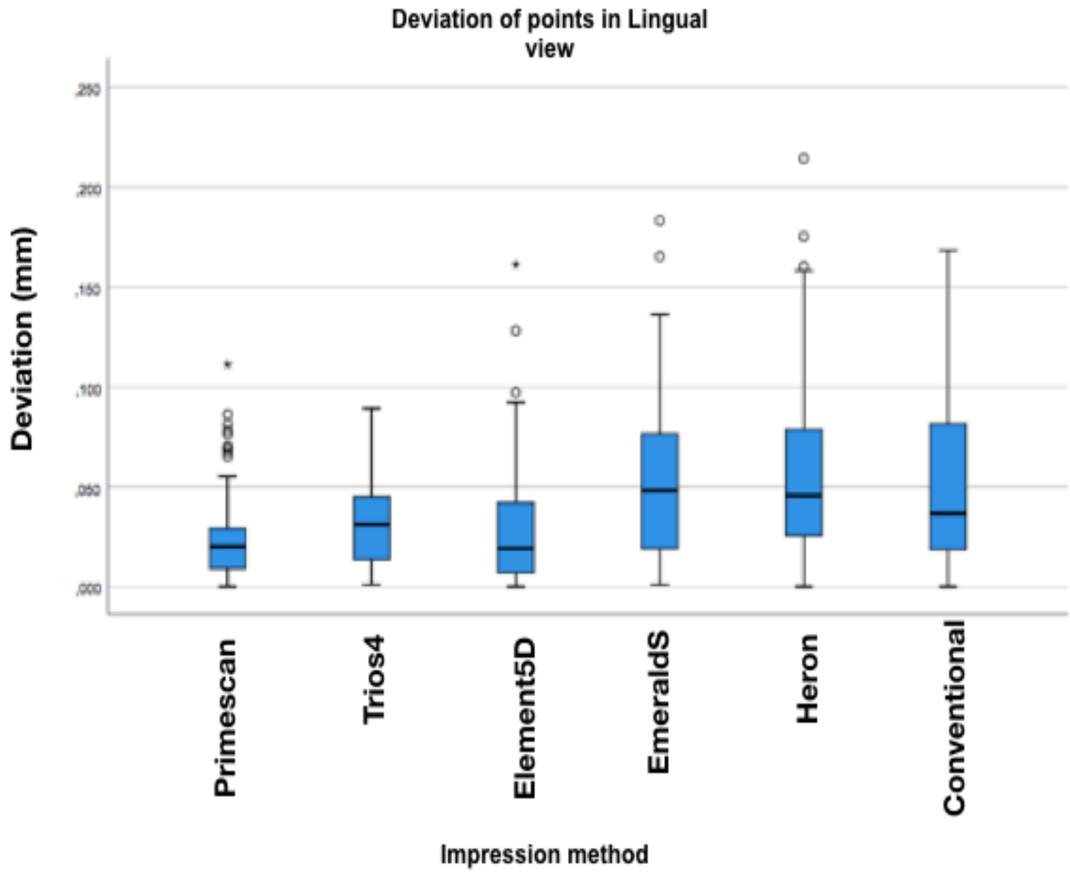


Figure4. 34 Boxplots representing the deviation of selected points in Lingual view for each impression group in the overall analysis.

The median deviation of the devices:

Itero Element5D-Align Technology-Cadent (0.019mm, IQR=0,035) < **Primescan** (0.020mm, IQR=0.020) **Trios 4 -3Shape** (0,031mm, IQR=0,032) < **Conventional impression group** (0,037mm, IQR=0,064)< **Heron ios-3disc** (0,046mm, IQR=0,054)< **Emerald S-Planmeca** (0,048mm, IQR=0,058) (Table 4.7)

Table4. 8 Man Whitney U test results for pairwise comparison of impression methods

Pairwise Comparisons of impression methods

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Primescan-itero	-29,187	26,849	-1,087	,277	1,000
Primescan-3shape	-82,146	26,849	-3,060	,002	,033
Primescan-Conventional	-149,721	26,849	-5,576	<,001	,000
Primescan-Planmeca	-171,117	26,849	-6,373	<,001	,000
Primescan-Heron	-184,579	26,849	-6,875	<,001	,000
itero-3shape	52,958	26,849	1,972	,049	,728
itero-Conventional	-120,533	26,849	-4,489	<,001	,000
itero-Planmeca	-141,929	26,849	-5,286	<,001	,000
itero-Heron	-155,392	26,849	-5,788	<,001	,000
3shape-Conventional	-67,575	26,849	-2,517	,012	,178
3shape-Planmeca	-88,971	26,849	-3,314	<,001	,014
3shape-Heron	-102,433	26,849	-3,815	<,001	,002
Conventional-Planmeca	21,396	26,849	,797	,426	1,000
Conventional-Heron	34,858	26,849	1,298	,194	1,000
Planmeca-Heron	-13,462	26,849	-,501	,616	1,000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.Asymptotic significances (2-sided tests) are displayed. The significance level is ,050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table4. 9 Simplification of results of Man Whitney U test

P value	Primescan	3shape	Conventional	Planmeca	İtero	Heron
Primescan		0,033	<0.01	<0.01	1.00	<0.01
3shape			0,178	0,014	0,728	0,002
Conventional				1.00	<0.01	1.00
Planmeca					<0.01	1.00
İtero						<0.01
Heron						

* A Man Whitney Test P<0.05

*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

The Kruskal-Wallis test revealed significant differences in trueness values among the six groups tested (P<0.05). A Man Whitney U test was performed to determine which paired groups the significant difference originated, and the findings are presented in Table 4.8.

The median deviation values of the Primescan group were significantly lower than those of the Trios 4 -3Shape group, Emerald S-Planmeca group, Heron ios-3disc group and the conventional impression group. (P<0.05)

The Trios 4 -3Shape group's median deviation values were significantly lower than those of the Emerald S-Planmeca group and Heron ios-3disc group. (P<0.05)

The median deviation values of the Itero Element5D-Align Technology-Cadent group were significantly lower than those of the Emerald S-Planmeca group, Heron ios-3disc group and conventional impression group. (P<0.05)

There were no significant differences in median deviation values among Trios 4 -3Shape group and the Itero Element5D-Align Technology-Cadent group. (P>0.05)

There were no significant differences in median deviation values between the Itero Element5D-Align Technology-Cadent group and the Primescan group. (P>0.05)

There were no significant differences in median deviation values between the Trios 4 -3Shape group and the conventional impression group. (P>0.05)

There were no significant differences in median deviation values between the Emerald S-Planmeca and conventional impression groups. (P>0.05)

There were no significant differences in median deviation values between the Heron ios-3disc group and the conventional impression group. (P>0.05)

There are no significant differences in median deviation values between the Heron ios-3disc group and the Emerald S-Planmeca group (P>0.05) (Table4.9)

4.4. Deviation of points in occlusal view

Table4. 10 Root mean square deviation values of selected lingual points of implants for impression groups (mm)

IOS	Nx	Median	IQR	Min	Max	Skewness
Primescan	120	0,014	0,020	0	0,115	2,203
3Shape	120	0,018	0,020	0	0,249	5,722
İtero	120	0,017	0,018	0	0,086	1,533
Planmeca	120	0,020	0,030	0	0,090	0,633
Heron	120	0,040	0,050	0	0,140	0,789
Conventional	120	0,040	0,060	0	0,151	0,860

As a result of the measurements, the median deviation of Primescan was 0.014mm.
(IQR=0.020, min=0mm, max=0.115mm)
The median deviation of Trios 4 -3Shape was 0,018mm.
(IQR=0,020, min=0mm, max=0,249mm)
The median deviation of Heron ios-3disc was 0,040mm.
(IQR=0,050, min= 0mm, max=0,140mm)
The median deviation of Emerald S-Planmeca was 0,020mm.
(IQR=0,030, min= 0mm, max=0,090mm)
The median deviation of Itero Element5D-Align Technology-Cadent was 0,017mm.
(IQR=0,018, min=0mm, max=0,086mm)
The median deviation of conventional impression group was 0,040mm.
(IQR=0,060, min=0mm max=0,151mm)

The median deviation was lowest in Primescan (0.020mm, IQR=0,035). Highest median deviation was found in conventional impression group (0,040mm, IQR=0,060) and Heron ios-3disc (0,040mm, IQR=0,050). (Table 4.10)

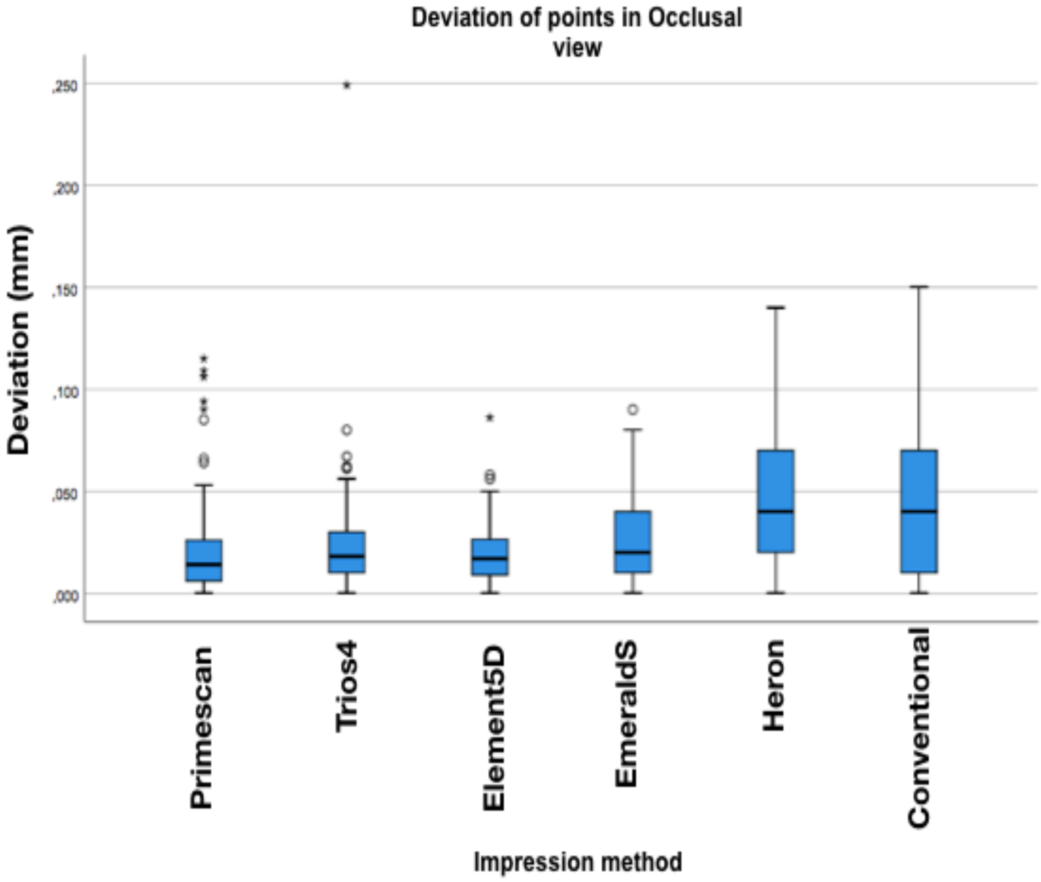


Figure4. 5 Boxplots representing the deviation of selected points in Occlusal view for each impression group in the overall analysis.

The median deviation of the devices:

Primescan (0.014mm, IQR=0.020)<**Itero Element5D-Align Technology-Cadent** (0.017mm, IQR=0,018) < **Trios 4 -3Shape** (0,018mm, IQR=0,020) < **Emerald S-Planmeca** (0,020mm, IQR=0,030) < **Conventional impression group** (0,040mm, IQR=0,060)=**Heron ios-3disc** (0,040mm, IQR=0,050). (Table 4.10)

Table4. 11 Man Whitney U test results for pairwise comparison of impression methods

Pairwise Comparisons of impression methods

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Primescan-itero	-22,829	26,811	-,851	,395	1,000
Primescan-3shape	-40,325	26,811	-1,504	,133	1,000
Primescan-Planmeca	-75,346	26,811	-2,810	,005	,074
Primescan-Conventional	-176,825	26,811	-6,595	<,001	,000
Primescan-Heron	-198,175	26,811	-7,391	<,001	,000
itero-3shape	17,496	26,811	,653	,514	1,000
itero-Planmeca	-52,517	26,811	-1,959	,050	,752
itero-Conventional	-153,996	26,811	-5,744	<,001	,000
itero-Heron	-175,346	26,811	-6,540	<,001	,000
3shape-Planmeca	-35,021	26,811	-1,306	,191	1,000
3shape-Conventional	-136,500	26,811	-5,091	<,001	,000
3shape-Heron	-157,850	26,811	-5,887	<,001	,000
Planmeca-Conventional	-101,479	26,811	-3,785	<,001	,002
Planmeca-Heron	-122,829	26,811	-4,581	<,001	,000
Conventional-Heron	21,350	26,811	,796	,426	1,000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is ,050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table4. 12 Simplification of results of Man Whitney U test

P value	Primescan	3shape	Conventional	Planmeca	İtero	Heron
Primescan		1.00	<0.01	0,074	1.00	<0.01
3shape			<0.01	1.00	1.00	<0.01
Conventional				0,002	<0.01	1,00
Planmeca					0,757	<0.01
İtero						<0.01
Heron						

* A Man Whitney Test P<0.05

*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

The Kruskal-Wallis test revealed significant differences in trueness values among the six groups tested ($P<0.05$). A Man Whitney U test was performed to determine between which paired groups the significant difference originated, and the findings are presented in Table 4.11

The median deviation values of the Primescan group were significantly lower than those of the Heron ios-3disc group and conventional impression group. ($P<0.05$)

The Trios 4 -3Shape group's median deviation values were significantly lower than those of the Heron ios-3disc group and conventional impression group. ($P<0.05$)

The median deviation values of the Itero Element5D-Align Technology-Cadent group were significantly lower than those of the Heron ios-3disc group and conventional impression group. ($P<0.05$)

The median deviation values of the Emerald S-Planmeca group were significantly lower than those of the Heron ios-3disc group and conventional impression group. ($P<0.05$)

There were no significant differences in trueness values among Trios 4 -3Shape group, Itero Element5D-Align Technology-Cadent group, Emerald S-Planmeca group and Primescan group. ($P>0.05$)

There were no significant differences in median deviation values between the Heron ios-3disc group and the conventional impression group. ($P>0.05$) (Table4.12)

4.5. Precision

Table4. 13 Mean deviation values and St. Deviation for groups in terms of Precision

					95% Confidence Interval for Mean	
IOS	Nx*	Mean	St. Deviation	St. Error	Lower bound	Upper bound
Primescan	60	0,04543	0,038310	0,004946	0,03554	0,05533
3Shape	60	0,06557	0,053629	0,006923	0,05171	0,07942
İtero	60	0,04190	0,026821	0,003463	0,03497	0,04883
Planmeca	60	0,09707	0,061036	0,007880	0,08130	0,11283
Heron	60	0,11782	0,060682	0,007834	0,10214	0,13349
Conventional	60	0,07988	0,049049	0,006332	0,06721	0,09255

According to the absolute statistical results of the deviations of the intraoral scanners from their mean values in each scan, the repeatability (precision) levels were;

The mean precision was 0,04543± 0,038310 mm for the Primescan group.

The mean precision was 0,06557± 0,053629 mm for Trios 4 -3Shape group.

The mean precision was 0,04190± 0,026821 mm for the Itero Element5D-Align Technology-Cadent group.

The mean precision was 0,09707± 0,061036 mm for the Emerald S-Planmeca group.

The mean precision was 0,11782± 0,060682 mm for the Heron ios-3disc group.

The mean precision was 0,07988± 0,049049 mm for Conventional impression group. (Table4.13)

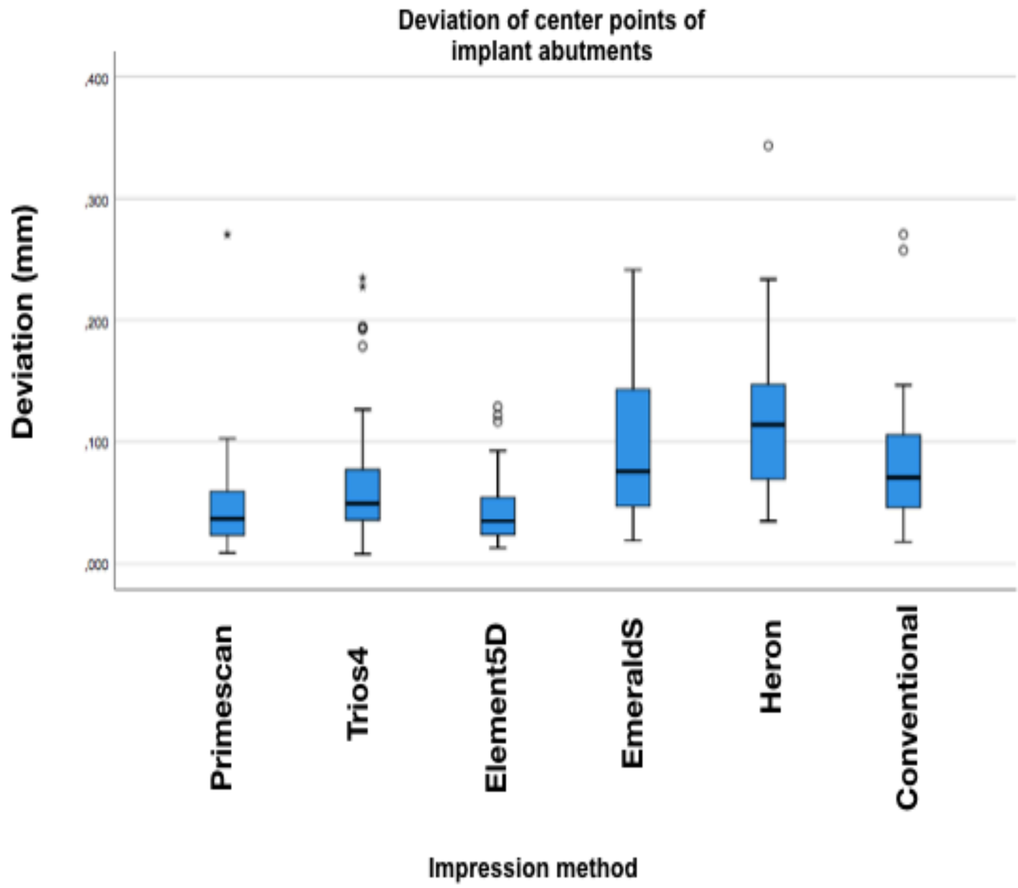
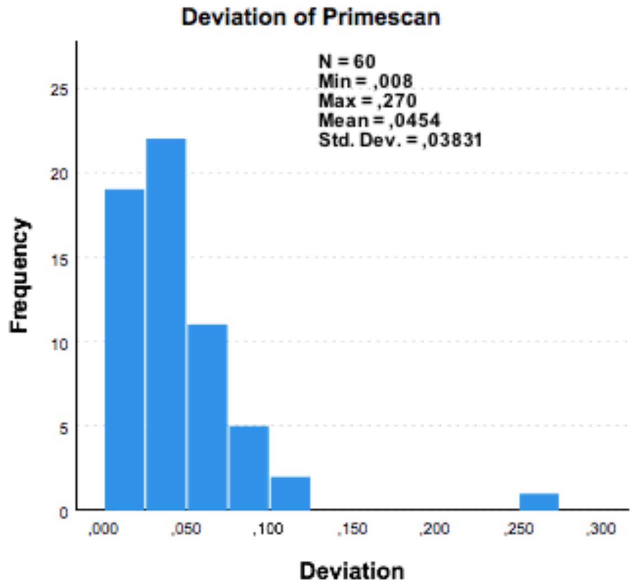


Figure4. 6 Boxplots representing the precision values for each impression group in the overall analysis.

The mean precision of the devices:

Itero Element5D-Align Technology-Cadent (0,04190± 0,026821 mm)> **Primescan**(0,04543± 0,038310 mm)> **Trios 4 -3Shape**(0,06557± 0,053629 mm)> **Conventional impression group**(0,07988± 0,049049 mm)> **Emerald S-Planmeca**(0,09707± 0,061036 mm)> **Heron ios-3disc**(0,11782± 0,060682 mm) (Figure4.6)

4.6. Deviation analyses for Primescan



IOS	Nx*	min	max	Mean	Std.Dev	Median	IQR	Skewness
Primescan	60	0,008	0,27	0,0454	0,03831	0,036	0,037	3,64

Figure4. 7 Deviations of Primescan(mm)

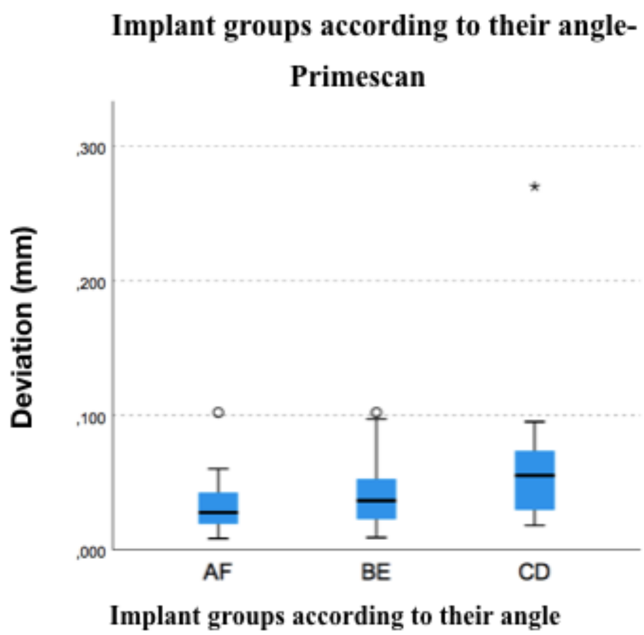


Figure4. 8 Boxplots representing the 3D deviation of Implant groups according to their angle-Primescan(mm)

Table4. 14 Man Whitney U test results for pairwise comparison of implant groups according to their angle-Primescan

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
AF-BE	-6,675	5,521	-1,209	,227	,680
AF-CD	-14,100	5,521	-2,554	,011	,032
BE-CD	-7,425	5,521	-1,345	,179	,536

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2- sided tests) are displayed. The significance level is 0,050

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table4. 15 Simplification of results of Man Whitney U test

P value	AF	BE	CD
AF		0,680	0,032
BE			0,536
CD			

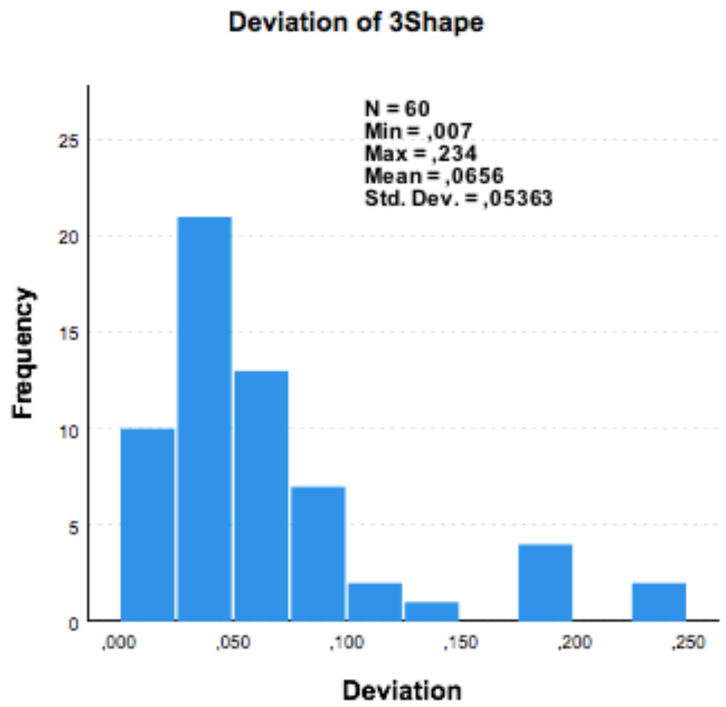
* A Man Whitney Test P<0.05
*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

The deviation values of the AF group were found to be significantly lower than the deviation values of the CD group. (P<0.05)

There was no statistically significant difference in between BE group and CD group. (P>0.05)

There was no statistically significant difference in between AF group and BE group. (P>0.05) (Table4.1)

4.7. Deviation analyses for 3SHAPE-TRİOS 4



IOS	Nx*	min	max	Mean	Std.Dev	Median	IQR	Skewness
3Shape	60	0,007	0,234	0,0656	0,05363	0,048	0,042	1,76

Figure4. 9 Deviations of 3Shape Trios4 (mm)

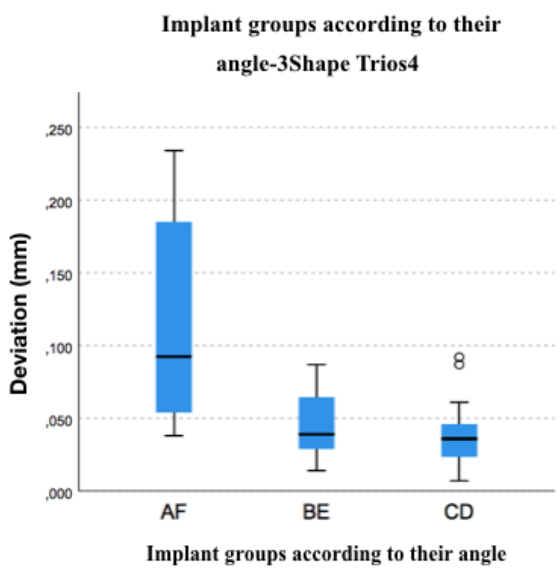


Figure4. 10 Boxplots representing the 3D deviation of Implant groups according to their angle-3Shape Trios 4 (mm)

Table4. 16 Man Whitney U test results for pairwise comparison of implant groups according to their angle-3Shape Trios4

Sample 1-Sample 2	Test Statistic	Std. Error	Statistic	Sig.	Adj. Sig.[a]
CD-BE	5,075	5,520	,919	,358	1,000
CD-AF	25,000	5,520	4,529	<,001	,000
BE-AF	19,925	5,520	3,609	<,001	,001

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2- sided tests) are displayed. The significance level is 0,050

a. Significance values have been adjusted by the Bonferroni correction for multipletests.

Table4. 17 Simplification of results of A Man Whitney U test

P value	AF	BE	CD
AF		0,01	<0,001
BE			1,00
CD			

* A Man Whitney U Test P<0.05
*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

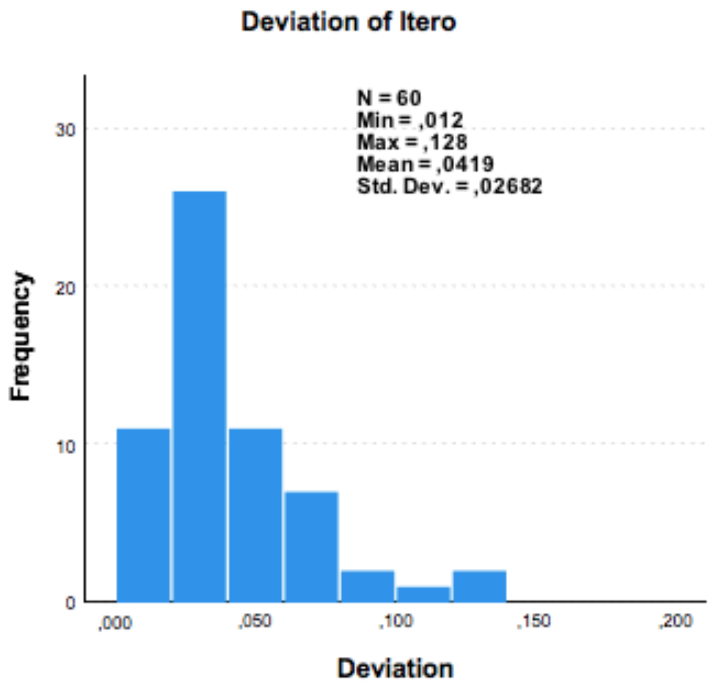
The deviation values of the BE group were found to be significantly lower than the deviation values of the AF group. (P<0.05)

The deviation values of the CD group were found to be significantly lower than the deviation values of the AF group. (P<0.05)

There was no statistically significant difference in between BE group and CD group. (P>0.05)

(Table4.17)

4.8. Deviation analyses for Itero Element5D



IOS	Nx*	min	max	Mean	Std.Dev	Median	IQR	Skewness
İtero	60	0,012	0,128	0,0419	0,02682	0,034	0,031	1,482

Figure4. 11 Deviations of Itero Element 5D (mm)

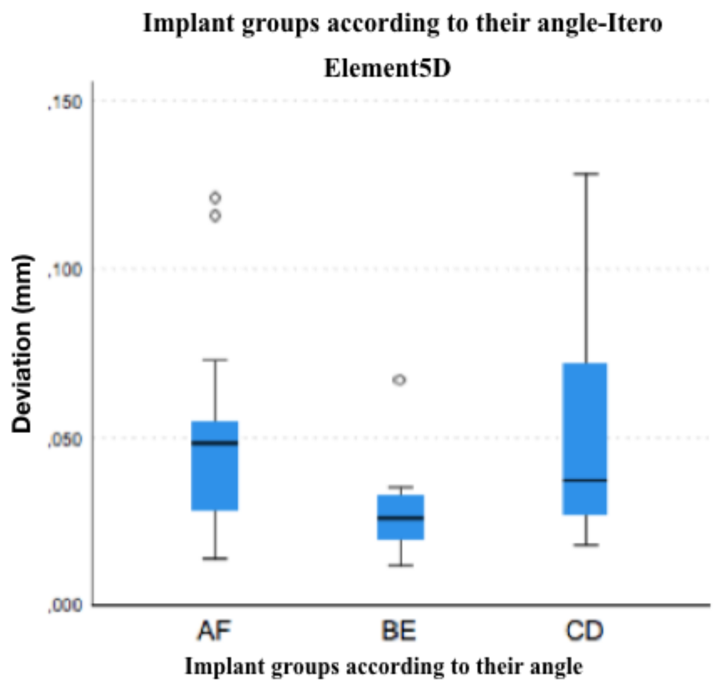


Figure4. 12 Boxplots representing the 3D deviation of Implant groups according to their angle-Itero Element 5D (mm)

Table4. 18 Man Whitney U test results for pairwise comparison of implant groups according to their angle-Itero Element 5D

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
BE-AF	15,550	5,518	2,818	,005	,014
BE-CD	-16,475	5,518	-2,986	,003	,008
AF-CD	-,925	5,518	-,168	,867	1,000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2- sided tests) are displayed. The significance level is 0,050

a. Significance values have been adjusted by the Bonferroni correction for multipletests.

Table4. 19 Simplification of results of A Man Whitney U test

P value	AF	BE	CD
AF		0,014	1,00
BE			0,008
CD			

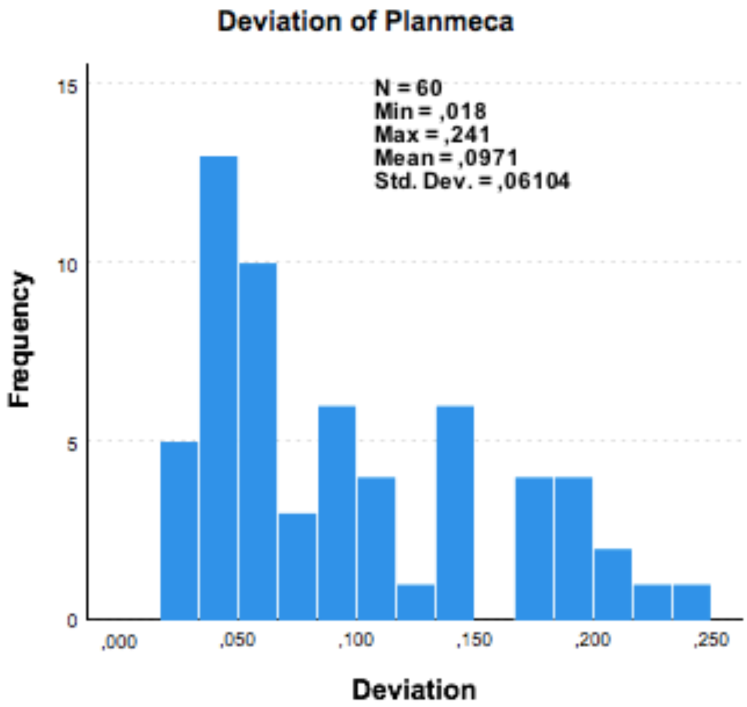
* A Man Whitney U Test P<0.05
*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

The deviation values of the BE group were found to be significantly lower than the deviation values of the CD group. (P<0.05)

The deviation values of the AF group were found to be significantly lower than the deviation values of the CD group. (P<0.05)

There was no statistically significant difference between the CD group and the AF group. (P>0.05) (Table4.19)

4.9. Deviation analyses for Planmeca-EmeraldS



IOS	Nx*	min	max	Mean	Std.Dev	Median	IQR	Skewness
Planmeca	60	0,018	0,241	0,0971	0,06104	0,075	0,097	0,727

Figure4. 13 Deviations of Planmeca EmeraldS(mm)

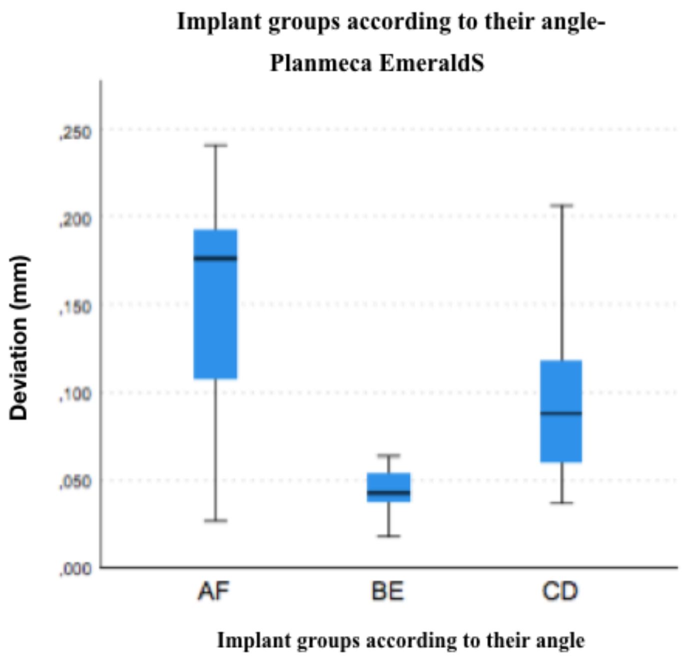


Figure4. 14 Boxplots representing the 3D deviation of Implant groups according to their angle-Planmeca EmeraldS (mm)

Table4. 20 Man Whitney U test results for pairwise comparison of implant groups according to their angle-Planmeca EmeraldS

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
BE-CD	-18,200	5,522	-3,296	<,001	,003
BE-AF	32,275	5,522	5,845	<,001	,000
CD-AF	14,075	5,522	2,549	,011	,032

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2- sided tests) are displayed. The significance level is 0,050

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table4. 21 Simplification of results of A Man Whitney U test

P value	AF	BE	CD
AF		<0,001	0,032
BE			0,003
CD			

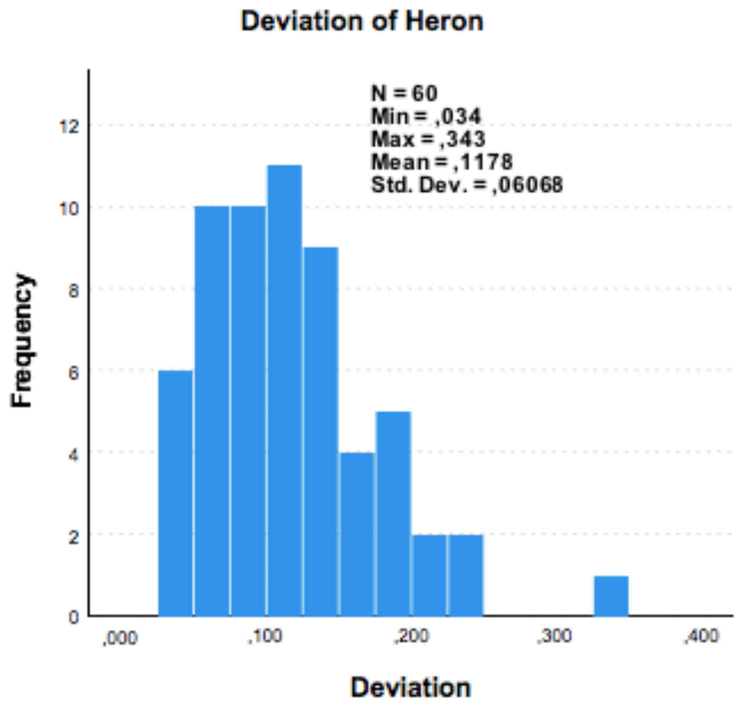
* A Man Whitney U Test P<0.05
*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

The deviation values of the BE group were found to be significantly lower than the deviation values of the AF group. (P<0.05)

The deviation values of the CD group were found to be significantly lower than the deviation values of the AF group. (P<0.05)

The deviation values of the BE group were found to be significantly lower than the deviation values of the CD group. (P<0.05) (Table4.21)

4.10. Deviation analyses for Heron IOS



IOS	Nx*	min	max	Mean	Std.Dev	Median	IQR	Skewness
Heron	60	0,034	0,343	0,1178	0,06068	0,11	0,080	1,063

Figure4. 15 Deviations of Heron(mm)

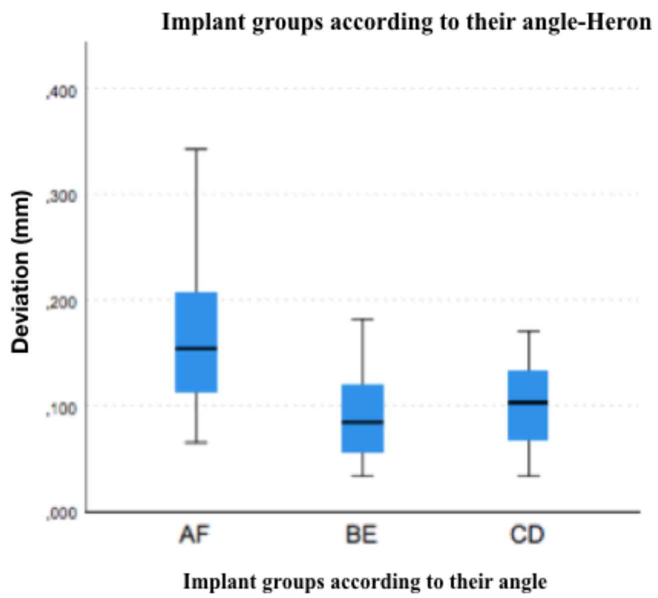


Figure4. 16 Boxplots representing the 3D deviation of Implant groups according to their angle-Heron (mm)

Table4. 22 Man Whitney U test results for pairwise comparison of implant groups according to their angle-Heron

Sample 1-Sample 2	Test Statistic	Std. Error	Statistic	Sig.	Adj. Sig.[a]
BE-CD	-3,425	5,522	-,620	,535	1,000
BE-AF	20,200	5,522	3,658	<,001	,001
CD-AF	16,775	5,522	3,038	,002	,007

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.

Asymptotic significances (2- sided tests) are displayed. The significance level is 0,050

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table4. 23 Simplification of results of A Man Whitney U test

P value	AF	BE	CD
AF		0,001	0,007
BE			1,00
CD			

* A Man Whitney U Test P<0.05

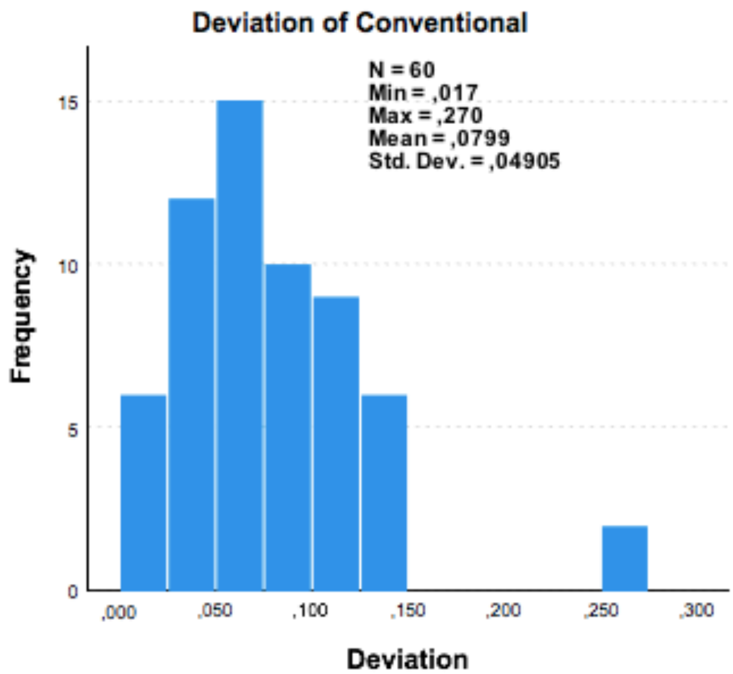
*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

The deviation values of the BE group were found to be significantly lower than the deviation values of the AF group. (P<0.05)

The deviation values of the CD group were found to be significantly lower than the deviation values of the AF group. (P<0.05)

There was no statistically significant difference in between CD group and BE group. (P>0.05) (Table4.23)

4.11. Deviation analyses for Conventional impression method



IOS	Nx*	min	max	Mean	Std.Dev	Median	IQR	Skewness
Conventional	60	0,017	0,27	0,0799	0,04905	0,07	0,06	1,711

Figure4. 17 Deviations of Conventional impression group(mm)

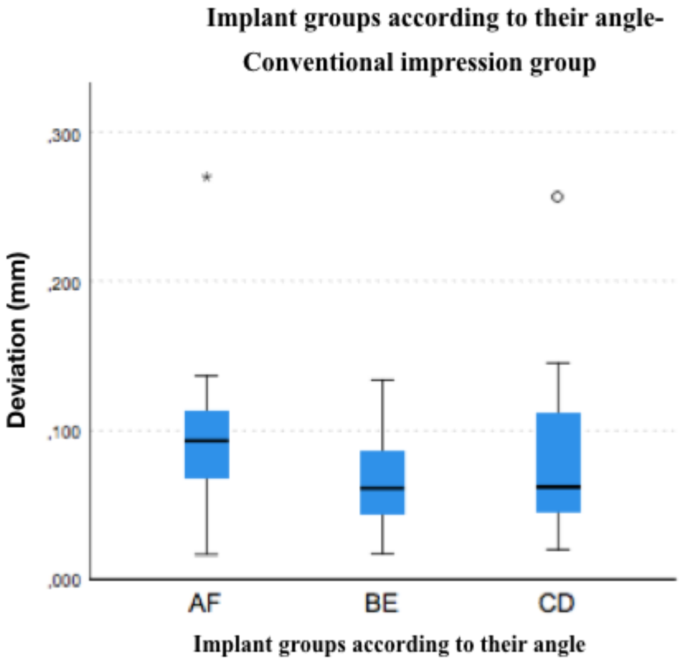


Figure4. 18 Boxplots representing the 3D deviation of Implant groups according to their angle-Conventional impression group (mm)

Table4. 24 Man Whitney U test results for pairwise comparison of implant groups according to their angle-Conventional impression group

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
BE-CD	-5,275	5,521	-,955	,339	1,000
BE-AF	11,525	5,521	2,087	,037	,111
CD-AF	6,250	5,521	1,132	,258	,773

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.

Asymptotic significances (2- sided tests) are displayed. The significance level is 0,050

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table4. 25 Simplification of results of A Man Whitney U test

P value	AF	BE	CD
AF		0,111	0,773
BE			1,00
CD			

* A Man Whitney U Test P<0.05
*Significance values have been adjusted by the Bonferroni correction a. for multiple tests.

There was no statistically significant difference in between the CD group and the AF group. (P>0.05)

There was no statistically significant difference in between the CD group and the BE group. (P>0.05)

There was no statistically significant difference in between the BE group and the AF group. (P>0.05) (Table4.25)

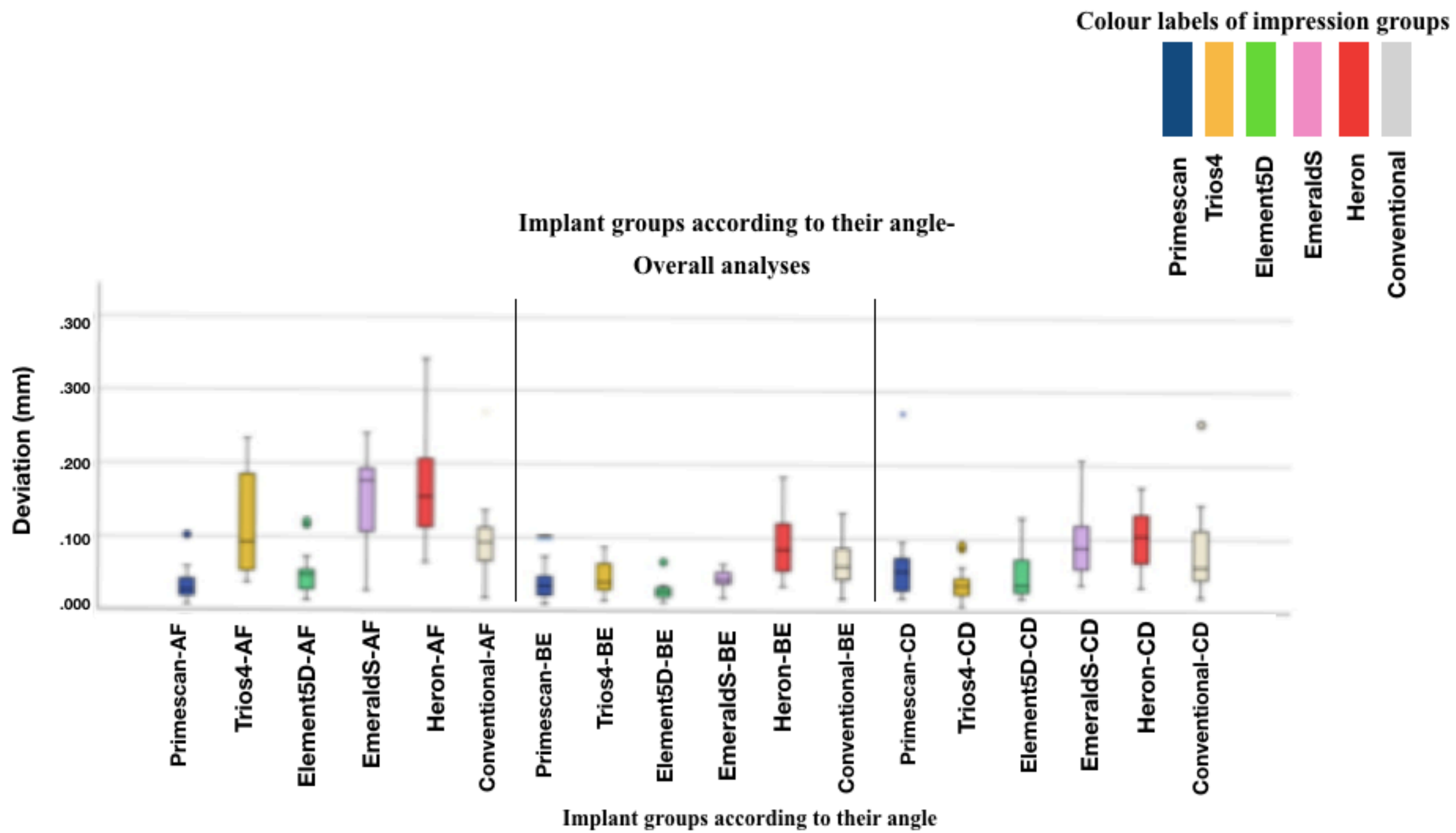


Figure4. 19 Boxplots representing the 3D deviation of Implant groups according to their angle-Overall analyses (mm)

5. DISCUSSION

Implant-supported prosthodontic restorations are currently a widely accepted treatment option for functional and aesthetic rehabilitation of partially and completely edentulous patients (147). One of the essential stages of achieving a successful implant-supported restoration is to clearly and accurately transfer the positions and angulations of the implants in the mouth to the working model (148). For implants whose position and angle have not been transferred to the working model, it is impossible to fabricate a passive fit implant-supported implant restoration. Passive fit indicates that the prosthetic infrastructure does not cause force or tension on the implant, abutment and bone around the implant; It is referred to as a fit between the prosthesis and the implant. The risk of many biomechanical complications, such as screw loosening and fracture, porcelain fracture, and bone loss around the implant, may develop due to the increase and accumulation of stress at the prosthesis-abutment and bone interfaces around the implant (128). The passive fit of an Implant-supported fixed dental prosthesis (IFDP) may be essential for maintaining a healthy bone-implant interface and is crucial to its long-term success. Even though a perfect passive fit is still unachievable, achieving the best fit is essential for avoiding mechanical and biological complications (137).

With the advancement of digital technology, the transition to digital systems in the dental diagnosis and treatment phases has accelerated. As a result of the impact of technological advances and the digital age on dentistry, intraoral digital scanners have been developed and integrated with various treatments. The development of computer-assisted design and computer-assisted manufacturing (CAD-CAM) technology has made it a viable alternative to conventional methods for fabricating IFDPs. The introduction of intra-oral scanners (IOSs) into fixed and implant prosthodontics has numerous advantages, such as eliminating tray selection, decreased risk of distortion during impression making, pouring, disinfecting, and shipping to the dental laboratory, and increased patient comfort and acceptance (92).

CAD/CAM systems have simplified working methods and made using newer and better materials possible. As the scanners' features have improved over time, intraoral scanners are now used to produce single and multi-unit, implant and tooth-supported restorations.

They have been integrated into daily dental practice. The aim of the development of CAD/CAM systems in prosthetic procedures is to eliminate conventional impression methods, to design the restoration using a computer according to its natural anatomy and functions, to produce the restoration in a single session, to improve the quality of the restoration and to provide a better aesthetic. In addition, digital methods offer numerous benefits, including material savings, increased patient comfort, shorter procedure times, and faster communication with the laboratory environment (149).

Examining the literature, it is possible to state that there are few studies on intraoral scanners, which are part of digital systems, due to their short history. However, more studies are being conducted every day. The majority of studies compare digital and conventional impression methods (150) (7) (64) (16) (151). As manufacturers develop newer and more advanced intraoral scanner systems daily, the current literature on these devices is limited but can be expanded over time. The present study aims to contribute to this gap in the literature. In the literature, studies show different deviation ranges. This may be due to difficulties in study standardization. Rutkunas et al. (152) conducted a literature review up to 2016 and discovered 16 studies that examined the accuracy of intraoral scanners on dental implants in cases of complete edentulism. These studies examined the iTero, True Definition, Trios, Lava Cos, CEREC, Carestream, and Planmeca scanner systems. The studies included a range of 1 to 8 implants. Linear deviations (means) of IOS ranged from 6 to 337 µm. Schmidt et al. (153) conducted a systematic literature review up to 2021 and discovered that Eight publications between 2014 and 2021 matched the review criteria. However, there were considerable differences between the study designs. In the studies, the number of implants ranged from 1 to 6, and the number of patients ranged from 10 to 39. These studies examined the iTero, True Definition, and Trios scanner systems. The oldest study in 20014 revealed the most significant deviation for linear distances at 1000 ± 650 µm, while the other studies reported data in the range of 360 ± 46 µm to 40 ± 20 µm. Flugge et al. conducted meta-analyses with 63 studies on the accuracy of conventional and digital implant impressions. Conventional impressions involved edentulous situations and implants placed along the entire dental arch. It resulted in linear and surface deviations of 97.1 µm. Digital impressions of edentulous jaws with parallel implants placed over the entire dental arch, resulting in linear and surface deviations of 51 µm. Albanchez et al. (154) conducted a systematic review to evaluate the in vitro accuracy of dental implant impressions taken with an intraoral scanner compared with impressions taken with conventional techniques. Six of the fifteen in vitro investigations simulating CE reported improved accuracy with digital impression systems, four reported no difference, and five reported greater accuracy with conventional impression systems. In our study, five different intraoral scanners and conventional impression methods currently used and available are evaluated in vitro regarding trueness and precision. Sixty experimental groups, ten from each system, were compared with the control group in terms of trueness and compared. Each experimental group with group self-evaluated in terms of precision. Only some studies are testing the accuracy of digital impressions for implant impressions in edentulous jaws, including the intraoral scanner systems we reviewed.

The material from which the reference model is fabricated is vital for the accuracy results of the impressions. To find a suitable material to manufacture a reference model, dental literature barely addresses the subject. Various materials have different properties that must match the objectives of the chosen study. Materials such as stainless steel (103) (155), cobalt-chromium alloy (10), dental stone (156) (157), polyurethane (158) (68), epoxy resin (136) and pink acrylic resin (92) were used, to fabricate the reference models in previous studies. Although metal-based models exhibit favorable physical and mechanical properties, the complexity of placing dental implants in the model and the reflection of light from surface features resulted in avoiding metal as the fabrication material in the present study (68). A dental stone was a second alternative. However, stone models are fragile and susceptible to water absorption, making them sensitive to dampness. On the other hand, the matt surface of the stone models makes it easier for the intra-oral scanner to record the structure (68) (109). Polyurethane and epoxy resin are extremely precise materials that would be preferable to stone. Polyurethane material is a reasonable choice for this reference model due to its affordability and ease of implant insertion (159). Our study used the lower jaw polyurethane model to ease production and reflect the anatomical conditions.

The accuracy of digital impressions for implant-supported prostheses is affected by several aspects discussed in the literature. These include the intraoral scanner's technology, the device's software, the operator's performance and experience, the scanning pattern and protocol, the properties of the scan body, and clinical factors (30) (152).

Gimenez et al. (92) concluded from an in vitro study that, even though an inexperienced operator takes longer to scan, experience does not always affect accuracy. In contrast, a different study by the same authors, Gimenez et al. (107), evaluated the clinical characteristics that affect the accuracy of digital impression-taking on the implant. It was found that operator experience increases the accuracy of impression-taking. However, that 15 scans are sufficient to reach the learning curve. Revell et al. (160) investigated operator experience on five different scanner systems in a maxilla with five implants and concluded that operator experience improves scanner accuracy. In our study, all of the conventional impressions and digital impressions were taken by a single operator. Before the impressions, the manufacturer's representative provided theoretical information on the functioning of the scanners, and 10 test scans were performed on each scanner. In this method, we attempted to eliminate the variable of operator experience from our analysis.

The number of studies examining the effect of scanning strategies on digital impression accuracy is limited in the literature. Various studies typically cite "manufacturer's advice" as the justification for the chosen scanning method (116) (161) (162) (68) (158). Müller et al. applied three scanning strategies with a scanner on a model. No significant difference was observed between the three-dimensional models obtained due to scanning with different strategies (100). Mennito et al. (163) applied five scanning strategies with six intraoral scanners. At the end of the study, it was reported that the scanning strategies did not significantly affect the accuracy of the result data. Latham et al. (164) evaluated four different scanning strategies with four different intraoral scanners and reported that different scanning strategies affected the results in some scanners but not others. Ender et al. (103) evaluated the accuracy of various scanning strategies. The authors made use of three IOSs (Lava COS; Cerec Bluecam, BC; iTero, CiT) and six scanning techniques: COS-straight (camera is straight and moves occlusal, orally, and buccally), COS-cross (camera moves from side to side along the dental arch in a "zig-zag" fashion), BC-top (optical impression only from an occlusal view), BC-diag (camera is angled by 30 and moves buccally and orally), BC-rot (same as BC-diag, but starts occlusal and then moves buccally (optical impression of dental arch buccally-orally and additional capturing of each preparation at a different angle). The trueness of COS-straight was 45.8 µm, COS-cross 90.2 µm, BC-top 52.5, BC-diag 29.4 µm, BC-rot 23.3 µm, CiT 35 µm. The study concluded that the choice of scanning strategy significantly impacts the accuracy of full-arch scanning, which also depends on the proper scanning protocol. In our study, we did not aim to investigate the effects of scanning strategies on the efficiency of digital scanners. All scans were performed following the manufacturer's instructions as in the aforementioned studies above.

Since a conventional impression-taking method was also included in our study, the literature regarding the most recommended conventional materials for multiple-implant impressions was evaluated. In the literature, PVS and polyether are the most commonly used impression materials for implant impressions (165).In addition to studies showing that polyether produces the best outcomes (166) (167) (59), it is also possible to find studies showing that there is no significant difference between polyether and PVS material (35) (168) (169) (170). Sorrentino et al. (31) reported that polyether impression material provided superior outcomes for parallel implants, but PVS impression material provided superior results for angled implants. In light of Sorrentino et al.’ s study, PVS was chosen as conventional impression material. Conventional impression methods that have been used and developed for many years during the production of implant-supported restorations can be classified as direct and indirect techniques. In the literature, numerous comparisons of the superiority of different techniques exist. Researches indicates that the direct technique is superior to the indirect technique (167) (171) (172) (173) (174), but there are other studies demonstrating that there is no meaningful difference between the two (175) (176) (177) (31) (168). The direct impression technique is a preferred method to accurately transfer the intraoral position of the implants to the laboratory environment, especially when the number of implants is more than four and the implant angles are not parallel. However, the most critical disadvantage of the technique is the possibility of rotation of the implant transfer copings during unscrewing or re-screwing of the impression copings with the implant analog while the tray is in the mouth. The solution to overcome this disadvantage is splinting the impression posts to each other (178).In studies in which the number of implants is increased, or complete edentulism is simulated, it is seen that the splinting of the impression posts increases the accuracy of the impression to a statistically significant degree (179) (180). In a systematic review of conventional implant impressions, Papaspyridakos et al. (181) identified 22 studies showing that splinting significantly increased impression accuracy in both partial and complete arch implant cases. In our study, custom open impression trays were created for each model, and impression posts were splinted together. Direct impression method and PVS impression material were employed to obtain the conventional impression.

A further influence can be attributed to the scan body employed. Regardless of the manufacturer, an IOS-detectable structure must be utilized. Moreover, only scan bodies stored in the software library of the scanner or accompanying CAD software should be used (182). Most scan bodies commercially accessible are made of polyetheretherketone (PEEK) or titanium. At the same time, the body of the scan body may also comprise aluminum alloy and other resins. To increase the accuracy of scan bodies, it is critical to consider these materials' machinability and manufacturing tolerances. In a study comparing three alternative scan body geometries, Revilla-Leon et al. (183) found that the shape of the scan body greatly affected intraoral scanner performance. According to Flugge et al. (97), the geometry of the scan body influences digital scanning efficiency, while the scanning body's orientation does not. Motel et al. (184) analyzed the influence of scan body design and scanning approach on accuracy. In contrast to irregular scan bodies with indents, cylindrical scan bodies with smoother surfaces exhibited lower deflection values. In addition, it has been suggested that a single-stage scanning method (without a separate soft tissue scan) may be favored in clinical practice due to its markedly superior outcomes. In our study, we did not aim to investigate the effects of scan body designs on the effectiveness of digital scanners. PEEK material scan bodies from Straumann, CARES Mono (Straumann AG, Basel, Switzerland) were used as scan bodies.

It is possible to find studies investigating the effect of implant placement depth on impression accuracy. Arcuri et al. (185) evaluated the impact of implant depth on digital impression, placing the implants subgingivally (3 and 6 mm subgingival). It was discovered that implant depth did not affect the accuracy of digital impressions. However, a different study by Gimenez-González et al. (107), in which implants were placed subgingivally (2 and 4 mm sub-gingivally), claims that the amount of visible scan body affects the accuracy of digital impressions; therefore, the depth of the implant should be taken into account when selecting the scan body design. Since our study did not aim to investigate the effect of implant placement depth on digital impression accuracy, all implants were placed in our model with a placement depth of 1.5 mm.

There are studies in the literature where ambient lighting conditions are considered a factor that can affect digital impression accuracy. Revilla-Leon et al. observed intraoral scanner activities under different ambient lighting conditions. Dental unit light (10,000 lux), room light (1003 lux), daylight (500 lux) and darkness (0 lux) were compared, and the room light environment gave significantly better results in full arc scans. The dental unit light environment in regional scans gave significantly better results (186). In another study by Revilla-Leon et al. (117), three different intraoral scanner models were evaluated for their accuracy under four different ambient lighting conditions, and it was reported that the ideal ambient lighting varied depending on the intraoral scanner device model; dental unit and room lighting for the iTero Element device, dark environment for the CEREC Omnicam device and room lighting for the Trios 3 device gave the best results. All scans in our study were performed under room lighting. The limitations of our study include the inability to standardize environmental factors such as the lux value of ambient lighting, temperature, pressure and humidity due to the different locations of the laboratories and clinics where intraoral scanners are located.

Different techniques are proposed and used in the literature to determine impression accuracy. These techniques include virtually measuring linear or angular deviations or 3D surface deviations, checking the marginal fit between the implant abutments and the substructure of the implant-supported restoration, and determining the stress on the substructure using a strain gauge after the substructure of the implant-supported restoration is placed on the abutments (165).In our study, the virtual 3D deviation measurement method was preferred due to the high precision technique required by physical measurement methods and the digital nature of the test models obtained.

In the literature, there are many studies evaluating the digital impression efficiency by calculating the three-dimensional deviations between the implant/scan body structures in the reference and test models in a virtual environment (19) (187) (188) (59) (160) (189). To calculate 3D surface deviations between implants, the reference and test models must be measured with a precise instrument. For this measurement, a coordinate measuring machine (190) (191) (192) (193) (122) (92) (91), microscope (170) (194), digital micrometer (195), profile projector device (196) and laser measuring device (197) were used in the studies. To assess the accuracy of the IOS and conventional materials included in the present study. Coordinate measuring machine (CMM) (CMM Contura G2 10/16/06 RDS- LineScan 2-25; Carl Zeiss Industrielle Mess Technik GmbH) with an accuracy of 1-3 microns was used for digitizing the reference model.

There are many studies in the literature where Geomagic Control X (North Carolina, United States of America) software is used to calculate deviation values between control and test groups (19) (198) (84) (157) (199) (200) (201). In the mentioned studies, as we did in our study, the data overlapped in the 'best-fit alignment' mode and the surface deviations were calculated. In our study, the registrations in the best-fit alignment mode were performed over the scan bodies. The reference data obtained from the CMM and the test data were superimposed in the virtual environment by software, and the deviation values on the scan bodies were calculated. The software uses the 'Root Mean Square' measure in this calculation.

In the literature, it is possible to come across studies evaluating intraoral scanners with different acquisition principles (132) (201) (59) (106) (44). There is no consensus on how the technology used impacts the scanner's effectiveness or which scanner technology produces the most successful results. Richert et al. (61). reported that intraoral scanners have clinical success regardless of the technologies they use, while Kachhara et al. (202). reported that scanners using Active Wavefront Sampling technology provide more accurate results as a result of their literature review. Still, current studies are insufficient, and further studies are needed. The devices utilized in our thesis study were chosen based on various factors, such as having different scanning technologies, being easily accessible, having been used in studies in the literature and thus being able to interpret the results obtained or having up-to-date technology taken into consideration. The intra-oral scanning devices we have included in our study have different acquisition methods. The Planmeca EmeraldS uses Red, green and blue lasers- Projected Pattern Triangulation. ITERO ELEMENTS 5D uses Parallel Confocal Microscopy. Trios 4 uses Ultrafast Optical Sectioning and confocal microscopy, and Dentsply-Sirona Primescan uses High-resolution Sensors and Shortwave Light with Optical High-Frequency Contrast Analysis for Dynamic Deep Scan (20 mm). Heron IOS uses active stereo imaging technology. There may be discrepancies in the accuracy of STL data collected by intraoral scanners employing distinct scanning and imaging techniques.

One of the critical issues in studies with intraoral scanners is the length of the area to be scanned. A difference in sensitivity and accuracy deviations between short arc scans in the entire arch and short edentulous cases has been reported as a finding in most studies (68) (110) (203) (204). The use of intraoral scanners in complete arch cases is a topic that is frequently investigated. Intraoral scanners, which obtain digital impressions using various non-contact imaging techniques, determine various reference points during scanning and can create 3D digital images by ensuring the continuity of scanning through these points (205). Using the mentioned reference points, the individual images captured by the scanners can be combined during this procedure. The more specific and numerous the reference points, the lower the bias in the scan data and the higher the success. These reference points can consist of tissues such as teeth and hard palate formations in the scanned areas. The main reason for the difference in impression accuracy between scanning a short arch with edentulous areas and scanning a fully edentulous arch is related to the smaller number of these reference points in the full arch cases (65) (206). Imbruglia et al. (88) compared Carestream 3600, Cerec Omnicam, Trios and True Definition intraoral scanners in terms of impression trueness in their study on two different models with partial edentulism with three implants and total edentulism with six implants. When the data from two different models were compared, it was determined that the impression accuracy of the partial edentulous model was higher than the total edentulous model in each impression group. The researchers stated that the increase in the number of implants and body distances increased the dimensional difference in digital impressions. Also, in full arc cases, the scan plane becomes a parabola that emerges from a single direction and rotates to the opposite arc. This horseshoe-shaped nonlinear structure with counter-rotating back rotation also generates a loss of reference at the corners where the rotation occurs (54). Therefore, intraoral scanners can be expected to produce more deviations in full arch cases than in short edentulous cases.

Examining the relevant literature reveals that the accuracy of intraoral scanner systems is evaluated on single tooth/implants, partially edentulous areas, and completely edentulous jaws. Nulty et al. (212) aimed to evaluate the complete arch scan accuracy (precision and trueness) of digital intra-oral scanners and lab scanners. In vitro study compared nine different intra-oral scanners (Omnicam 4.6; Omnicam 5.1; Primescan; CS 3600; Trios 3; Trios 4; Runyes; i500; and DL206) as well as four lab light scanners (Einscan SE; 300e; E2; and Ineos X5) to investigate the accuracy of each scanner by examining the overall trueness and precision. The Primescan had the best overall trueness (17.3 ± 4.9), followed by (in order of increasing deviation) the Trios 4 (20.8 ± 6.2), i500 (25.2 ± 7.3), CS3600 (26.9 ± 15.9), Trios 3 (27.7 ± 6.8), Runyes (47.2 ± 5.4), Omnicam 5.1 (55.1 ± 9.5), Omnicam 4.6 (57.5 ± 3.2), and Launca DL206 (58.5 ± 22.0). Although intraoral scanners used in digital impressions have demonstrated positive outcomes in vivo and in vitro research, many studies have highlighted the absence of data regarding their efficacy in patients with entire edentulousness, particularly in cases involving implants with significant edentulous area lengths (157) (207) (208) (209). Only some studies are testing the accuracy of digital impressions for implant impressions in edentulous jaws, including the intraoral scanner systems we reviewed, furthermore comparing them with the conventional impression methods.

Papaspyridakos et al. (157) placed five implants in a complete edentulous mandibular model and compared the accuracy of digital and conventional impressions. The Trios 3 device was preferred as the digital scanning device, while open tray impressions taken with polyether were preferred as the conventional impression method. While forming the conventional impression group, two subgroups were formed, splinted and non-splinted, to investigate the effectiveness of splinting the impression posts. Plaster models obtained from conventional impressions and reference models were digitized with a high-resolution scanner. Data were superimposed with the help of 3D software and evaluated the 3D deviation in the trueness parameter. As a result of the study, no significant difference was found between the digital and conventional impressions obtained from the splinted open impression. However, these deviation values are significantly lower than those obtained from the conventional impression taken without splinting. Papaspyridakos et al. stated that digital approaches are as accurate as conventional approaches. In our study, the median deviations of the Itero Element5D and Primescan groups were significantly lower than the conventional impression method. Furthermore, the median deviation values of the conventional impression method were significantly lower than those of the Heron IOS. Although the deviation values shown by all the impression methods in our study were lower than 150 μ, All the impression methods tested were clinically acceptable. Our findings are consistent with the results of Papaspyridakos et al.'s study.

Alikhasi et al. (210) evaluated the accuracy of the non-splinted open tray and closed tray methods with PVS and 3Shape Trios digital impressions. In an edentulous maxillary model, imprints were obtained of two straight and two distally slanted at 45-degree angles implants. With a linear deviation of 177.50 µm, the digital impression was determined to be the most accurate in terms of trueness. The open tray technique had a trueness value of 280 µm, while the closed tray technique had a trueness value of 885 µm. Menini et al. (11) evaluated the trueness of various impression techniques, including open tray method with polyether, splinted open tray method with polyether, closed tray method with polyether and True Definition Scanner as a digital impression on an edentulous jaw in which four implants were placed. Comparing the STL datasets of the master cast, traditional impression, and digital impression by CMM indicated statistically significant differences in accuracy. Digital implant techniques fared the best, whilst conventional implant procedures provided inconsistent outcomes. The digital approach was more precise than the conventional one. Albayrak et al. (123) compared the accuracy of implant impressions obtained with three different digital intraoral scanners (Carestream 3500, Trios 3 and Cerec Omnicam) with the conventional method (Polyvinyl siloxane) on an edentulous mandible. There was a significant difference between groups ($p < 0.0001$). They found that the impressions obtained with digital impression groups were more successful than those obtained with the conventional method. According to the results of the study, the impression accuracy was 123.06 ± 89.83 µm with CS 3500, 229.72 ± 121.34 µm with Cerec Omnicam, 209.75 ± 47.07 µm with Trios 3 and 345.32 ± 75.12 µm with the conventional method. The results of the studies above that mentioned the impression taken with the digital method is more accurate than the impression taken conventionally are similar to the results of some digital method groups we obtained from our study. Element5D, Primescan and Trios4 groups provided more accurate impressions than the conventional group. However, the conventional impression group provided more accurate impressions than the EmeraldS and Heron groups.

Kosaga et al. (211) aimed to compare the accuracy between conventional and different intraoral scanner impression methods in terms of 3D deviation for a complete mandibular edentulous arch with five placed implants. Different impression techniques were compared: one conventional impression, CO (open-tray splint impression coping, polyether), and three groups of intraoral scanners, TS (Trios 4), IT (iTero Element 2), and PS (Primescan). An extraoral scanner (E4 scanner) was used for digitizing the reference model as a control group. Scan body positions were compared with 3D deviation using a 3D analysis software program (Geomagic ControlX) with the best-fit alignment technique. The main selected areas on each scan body were superimposed during superimposition procedures. The root means square (RMS) was calculated.3D deviation of the Trios 4 (52.14 ± 3.88 µm), Primescan (57.24 ± 2.05 µm), iTero (67.72 ± 7.18 µm), and the conventional group (141.86 ± 5.58 µm). For precision, the mean RMS for 3D deviations was Trios 4 (19.39 ± 3.61 µm), Primescan (28.58 ± 8.03 µm), iTero (67.72 ± 7.18 µm), and evaluated in the conventional group (49.40 ± 13.39 µm). For complete-arch implant impressions, digital impression techniques have demonstrated greater accuracy than conventional impression techniques. The splinted open-tray impression approach had the most 3D variation. The result that digitally taken impressions are more accurate than measurements taken with conventional impressions is similar to the results obtained from our study. However, even though there is no significant difference between them, new generation Itero Element5D and Primescan have provided a more accurate impression than Trios 4 in our study. The variations in accuracy may be attributable to the various scanning methods and research model designs.

Ochoa-López et al. (213) aimed to evaluate the accuracy of seven IOSs, including Primescan and Element5D, under five levels of ambient lighting illuminance. The master model consists of an edentulous cast with four implants. Under various lighting conditions, the optimal median trueness and precision values for each IOS group were measured. According to the results, the impression trueness was found 34.0 ± 3.3 µm for Trios3, 34.9 ± 13.0 µm for Cs3700, 34.5 ± 7.1 µm for Element 5D, 36.2 ± 5.1 µm for i500, 69.5 ± 24.0 µm for Cs3600, 37.4 ± 37.3 µm trueness for Primescan and 34.8 ± 2.2 µm for i700.Furthermore, the repeatability was found 24.5 ± 14.9 µm for Trios3, 19.2 µm for Cs3700, 25.9 ± 7.6 µm for Element5D, 21.4 ± 6.8 µm for i500 ,36.6 ± 20.1 µm for Cs3600, 26.2 ± 26.2 µm for Primescan and 15.4 ± 5.0 µm for i700. In the study by Ochoa-López et al., Trios 3 gave the most accurate result in terms of trueness, while in our study, Itero Element5 and Primescan were more accurate than Trios 4, the new generation of Trios 3. In addition, while the i700 device showed the highest repeatability value in this study, the highest repeatability value in our study was obtained with the Itero Element5D. This may be attributed to differences in conditions of ambient lighting between the two studies.

Mangano et al. (214) aimed to evaluate the accuracy of different intraoral scanners on implant impressions in edentulous jaws and compared 12 different devices, including EmeraldS, Itero Element5D, Primescan, Trios 3 and Virtuo Vivo. A digital model was obtained by scanning an upper jaw model with eight implants with a desktop scanner (7Series, Dental- wings, Montreal, Canada) as a reference. The scan data from the test groups were superimposed with the reference data in 'best-fit' mode on the Geomagic software, and three-dimensional deviation values were calculated. The values were 31,4 µm for Itero Element5D,76 µm for Emerald, 52,9 µm for EmeraldS,31.5 µ for Medit i500, 38.4 µ for Primescan, 36.4 µ for Trios 3 and 43,8 µm for Virtuo Vivo. Similar to our study, Itero Element5D gave the most accurate results in terms of trueness, and there were no significant differences were found across Itero Element5, Trios 4, and Primescan devices. Consistent with the existing study, the deviation value obtained in our study was

36μm for Primescan, 34μm for Itero Element5D, 48μm for Trios 4 and 75μm for Emerald S.

Kaya et al. (215) aimed to compare the impression accuracy of 14 different intraoral scanners (Primescan, CS 3600, CS 3700, Trios 3, Trios 4, iTero 5D, iTero 2, Dental Wings, Emerald S, Emerald, Medit i500, BENQ, Heron, GC Aadva) on four implants placed complete edentulous upper jaw model. A statistically significant difference was found between the scanners ($p<0.05$). As a result of the study, it was observed that the scanner showing the least deviation for trueness compared to the reference scanner was Sirona Primescan, and the scanner showing the most variation was GC Aadva. According to the data obtained, when the consistency of the devices within themselves is evaluated, the scanner showing the least deviation was Sirona Primescan, and the scanner showing the highest variation was the 3Disc Heron.

Revell et al. (160) evaluated the impression accuracy of Medit i500, Trios 3, Trios 4, and Primescan devices on a maxilla with five implants resected from a human cadaver with experienced and inexperienced operators. Scan data and reference data taken by experienced and inexperienced operators in digital dentistry were superimposed on 'whole arch' and 'scan body only,' respectively. Linear measurements and 3D surface deviations were then evaluated on the scan bodies. The scanner ranking was Element 2(63 ±4.1 mm), i500 (57 ±3.6 mm, P=.443), TRIOS 4 (54 ±3.1 mm, P=.591), TRIOS 3 (40 ±3.1 mm, P<.01), Primescan (27 ±1.6 mm, P<.001) for the inexperienced operator and i500 (68 ±4.1 mm), Element 2 (58 ±4.0 mm, P=.141), TRIOS 3 (41 ±2.8 mm, P<.001), TRIOS 4 (35 ±3.3 mm, P=.205), Primescan (28 ±1.8 mm, P=.141) for the experienced operators. The results achieved from a group of experienced operators in Revel et al.'s study were compared to our own. Similar to our study, while no significant difference was seen between Trios 4 and Primescan, the average deviation of Trios 4 data was greater than that of Primescan data.

In the study by Knecthle et al. (216), digital impressions of the upper jaw model with six implants were obtained with four different scanners (Trios 3, Primescan, Trios Color, Omnicam, and Primescan), and these data were compared with reference data in terms of trueness. The most accurate scanner was found as Primescan with 54.8 μm. Similar to this study, in our study, high trueness values were obtained with Primescan, which gave similar values with Itero Element5D, which showed the highest trueness values. An evaluation of the studies in the literature, both among themselves and in conjunction with our study, has not led to a consensus on which scanner is more accurate and at which value of mean three-dimensional deviation they show in the relevant cases. This may be attributed to the presence of many factors affecting the accuracy of digital implant impressions and the difficulty in standardizing factors other than the ones tested in the studies.

For the present study, when the study's impression groups are tested against themselves, median deviation amounts of implant center points in trueness parameter,
deviation values obtained for Itero Element5D (0,034mm) is numerically lower than the deviation values obtained for Primescan (0.036mm), Trios 4 (0,048mm), Conventional impression group (0,07mm), Emerald S (0,075mm), Heron ios-3disc (0,11mm). There was no significant difference between the values of Itero Element5D and Primescan, Trios 4. In contrast, the values of Itero Element5D were significantly lower than those of the Conventional impression group, Emerald S and Heron.

The deviation value obtained for Primescan (0.036mm) is numerically lower than the deviation value obtained for Trios 4 (0,048mm), Conventional impression group (0,07mm), Emerald S (0,075mm), Heron ios-3disc (0,11mm), it is numerically higher than the deviation value obtained for Itero Element5D (0,0034mm). There was no significant difference between the values of Primescan and Itero Element5D, Trios 4. In contrast, the values of Primescan were significantly lower than those of the Conventional impression group, Emerald S and Heron.

The deviation value obtained for Trios 4 (0,048mm) is numerically lower than the deviation value obtained for the Conventional impression group (0,07mm), Emerald S (0,075mm), Heron ios-3disc (0,11mm), it is numerically higher than the deviation value obtained for Itero Element5D (0,0034mm) and Primescan (0.036mm). There was no significant difference between Trios 4 and Itero Element5D, Primescan, Conventional impression group, while the values of Trios 4 were significantly lower than those of Emerald S and Heron.

The deviation value obtained for the Conventional impression group (0,07mm) is numerically lower than the deviation value obtained for Emerald S (0,075mm), Heron ios-3disc (0,11mm), it is numerically higher than the deviation value obtained for Itero Element5D (0,0034mm), Primescan (0.036mm) and Trios 4 (0,048mm). The conventional impression group was significantly lower than Heron.

According to our data, the first null hypothesis, as ‘there is no significant difference in terms of trueness between digital impression method and conventional impression method and intraoral scanners have similar trueness values,’ was partially rejected.
There were significant differences in trueness between groups, and the Itero Element5D and Primescan groups have significantly lower deviation values than the conventional impression group. Also, the conventional impression group has a significantly lower deviation value than the Heron group.

Another factor related to impression accuracy is precision. Measurements of repeated scans were used to assess the precision. The mean precision was 0,04543± 0,038310 mm for the Primescan group, 0,06557± 0,053629 mm for Trios 4 -3Shape group, 0,04190± 0,026821 mm for Itero Element5D, 0,09707± 0,061036 mm for Emerald S, 0,11782± 0,060682 mm for Heron and 0,07988± 0,049049 mm for Conventional impression group. When the impression groups were compared in terms of precision, the highest repeatability was obtained with Itero Element5D, and the lowest repeatability was obtained with Heron.

In our study, 3D deviation amounts of the impression groups are analyzed based on the implant groups according to their angles. The Primescan group has the least deviation from the AF group, followed by the BE group and CD group. The deviation values of the AF group were found to be significantly lower than the deviation values of the CD group. There was no statistically significant difference between BE group and the CD group, and There was no statistically significant difference between the AF group and BE group. Based on our findings, it can be concluded that the device is negatively affected in total arc scans, during which the scan plane becomes a parabola originating from a single direction and returning to the opposite arc.

The Trios4 group has the least deviation from the CD group, followed by the BE group and AF group. The deviation values of the CD group were found to be significantly lower than the AF group's deviation values, and the CD group's deviation values were found to be statistically significantly lower than the deviation values of the AF group. However, there was no statistically significant difference between BE group and the CD group. Based on our findings, it can be concluded that the Trios4 device has some difficulties matching data at the scan start and end points in complete edentulism and a very long scan area.

The Itero Element5D group has the least deviation in the BE group, followed by the AF group and CD group. The deviation values of the BE group were found to be significantly lower than the deviation values of the CD group. Furthermore, the deviation values of the AF group were found to be significantly lower than the deviation values of the CD group. However, there was no significant difference between the CD and AF groups. Based on our data, it can be concluded that in the case of complete edentulism and a very long scan area, the Trios4 device has some difficulties matching data at the scan start and end points; thus, the parabola shape of the scan plane negatively affected the scan accuracy.

The EmeraldS group has the least deviation from the BE group, followed by the CD group and AF group. The deviation values of the BE group were found to be significantly lower than the deviation values of the CD and AF groups. The deviation values of the CD group were found to be significantly lower than the deviation values of the AF group. Based on our data, it can be concluded that in the case of complete edentulism and a very long scan area, the EmeraldS device has some difficulties matching data at the scan start and end points; thus, the parabola shape of the scan plane negatively affected the scan accuracy.

The Heron group has the least deviation amounts in the BE group, followed by the CD group and AF group. The deviation values of the BE group were found to be significantly lower than the AF group's deviation values, and the CD group's deviation values were s significantly lower than the deviation values of the AF group. Still, there was no statistically significant difference between the CD and BE groups. Based on our findings, it can be concluded that the Heron device has some difficulties matching data at the scan start and end points in complete edentulism and a very long scan area.

The conventional impression group has the least deviation amounts in the BE group, followed by the CD group and AF group. There was no statistically significant difference between the CD, AF, and BE groups. Based on our data, it can be concluded that the conventional impression group displayed a balanced pattern of deviation. The arc’s distance and parabola shape did not affect the conventional impression.

According to our data, our second null hypothesis that 'there is no difference in deviation values between implant groups according to their angles for each impression method' was partially rejected. Except for the conventional impression group, significant differences were found between each implant group in each impression method. This could be a result of the various scanning technologies utilized by the scanning devices.

In our study, the determination of ideal and acceptable deviations in impression was based on the American Dental Association's Specification No. 19, published on the properties of elastomeric impressions (144). According to these specifications, the ideal value is ±20 microns, while a value of ±150 microns is considered clinically acceptable. The deviation value obtained in our study for Primescan (36µm), Itero Element5D-Align Technology-Cadent (34µm), Trios 4 -3Shape (48µm), Conventional impression group (70µm), Emerald S-Planmeca (75µm), Heron ios-3disc (110µm). The deviation values shown by all the impression methods in our study were lower than 150 µm, which is the standard value for an acceptable impression. Therefore, All the impression methods tested were clinically acceptable.

Numerous in vivo experiments (151) (217) (218) utilizing intraoral scanners have found lower scanning accuracy due to the oral cavity's restricted range of motion and severe environmental conditions. In all in vitro investigations, including this one, an ideal intraoral scanning field is established under actual clinical conditions. Considering this circumstance, it is likely that intraoral scans performed in a patient's mouth in a clinical scenario will demonstrate a lower impression accuracy than our study (219) (220) .The scans applied in this study were performed in a laboratory environment, not in the intraoral environment where constant temperature and pH changes occur. For this reason, it is not possible to fully reflect the clinical conditions. The fact that the environmental conditions of the environments where the scans were performed were not standardized in terms of lighting, temperature, humidity and pressure can also be shown among the limitations of our study.

6. CONCLUSION

In this study, in which the impression accuracy of intraoral scanners and conventional impression systems actively used in the market were compared, and their trueness and precision were evaluated, the following conclusions were reached in this in vitro study:

1. According to our study, when the trueness of the impression methods within themselves is evaluated, it is observed that the scanner shows the least deviation is 'Itero Element5D(0.034mm),' and the scanner shows the most deviation is '3Disc Heron(0,11mm)'.
2. The median deviation values of the Primescan and Itero Element5D devices were significantly lower than the mean deviation values of the conventional impression method. ($P<0,05$)
3. The median deviation values of the conventional impression method were significantly lower than those of the Heron IOS. ($P<0,05$)
4. According to our study, when the precision of the devices within themselves is evaluated, it is observed that the scanner shows the highest repeatability as Sirona Primescan, and the scanner shows the lowest repeatability as '3Disc Heron'.
5. The deviation values shown by all the impression methods in our study were lower than 150 μ, which is the standard value for an acceptable impression. Therefore, All the impression methods tested were clinically acceptable.
6. In the literature, there are many factors affecting the accuracy of digital implant impressions. It is essential that these factors are taken into account for studies to support each other. Therefore, it's not surprising to see significant variation between the studies.
7. Digital impression technology is still developing; therefore, new in vivo and in vitro studies using new technologies are needed.

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8. APPENDICES

8.1. CURRICULUM VITAE

Kişisel Bilgiler

Adı	Ilgın	Soyadı	Özer

Öğrenim Durumu

Derece	Alan	Mezun Olduğu Kurumun Adı	Mezuniyet Yılı
Doktora	Protetik diş tedavisi	Yeditepe Üniversitesi	2023
Yüksek Lisans			
Lisans		Yeditepe Üniversitesi	2013
Lise		Mef Lisesi	2007

Bildiği Yabancı Dilleri	Yabancı Dil Sınav Notu (#)
İngilizce	

Başarılmış birden fazla sınav varsa (KPDS, ÜDS, TOEFL; EELTS vs), tüm sonuçlar yazılmalıdır

İş Deneyimi (Sondan geçmişe doğru sıralayın)

Görevi	Kurum	Süre (Yıl - Yıl)
Diş Hekimi	Klinik 32	10-
		-