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YEDITEPE UNIVERSITY  
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DEPARTMENT OF PROSTHODONTICS

**COMPARISON OF THE ACCURACY OF DIGITAL  
AND CONVENTIONAL IMPRESSION  
TECHNIQUES IN MULTIPLE IMPLANTS WITH  
DIFFERENT ANGULATIONS**

DOCTOR OF PHILOSOPHY THESIS

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## 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.

11.06.2024

Akanay OPUROĐLU



## DEDICATION

I dedicate this thesis to my parents for always being there for me and caring for me.



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## TABLE OF CONTENTS

APPROVAL	ii
DECLARATION	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
TABLE LIST	ix
FIGURE LIST	x
LIST OF SYMBOLS AND ABBREVIATIONS	xii
ABSTRACT	xiii
ÖZET	xv
1. INTRODUCTION AND PURPOSE	1
2. GENERAL INFORMATION	3
2.1. Impression Techniques for Implant Supported Prosthesis	3
2.1.1. Conventional Methods for the Impression of Implant Supported Prosthesis	3
2.1.1.1. Indirect Method (Closed Tray)	4
2.1.1.2. Direct Method (Open Tray)	4
2.1.1.3. Snap-on (Press fit) Method	5
2.1.2. Conventional Impression Materials Used for Implant Supported Prosthesis	6
2.1.2.1. Polysulfide	7
2.1.2.2. Polyether	7
2.1.2.3. Condensation Type Silicone (Type-C Silicone)	7
2.1.2.4. Polyvinylsiloxane (Type-A Silicone)	8
2.1.2.5. Polyvinyl Siloxane Ether	8
2.1.3. Abutment Level and Implant Level Impression	9
2.1.3.1. Abutment Level Impression	9
2.1.3.2. Implant Level Impression	9
2.1.4. Factors that Influence the Conventional Impression of Implant Supported Prosthesis	9
2.1.4.1. Impression Technique	9
2.1.4.2. Number of Implants and their Angulations	9
2.1.4.3. Implant Connection Levels (Implant Level and Abutment Level)	10
2.1.4.4. Type of Impression Coping	10

2.1.4.5. Type of Implant Connection	10
2.1.4.6. Implant Placement Depth	11
2.1.4.7. Cast Pouring Techniques	11
2.1.4.8. Machining Tolerance	12
2.1.5. Digital Impression Technique	12
2.1.6. CAD/CAM Systems and their Functional Elements	13
2.1.6.1. Design Software Program (CAD)	13
2.1.6.2. Fabrication (CAM)	14
2.1.7. Digital Data Acquisition by Using CAD/CAM Systems	14
2.1.8. Direct Methods of Impression for CAD/CAM Systems	15
2.1.8.1. The Space Between the Object and the Scanning Device	18
2.1.8.2. Image Capture and the Reflection of Light	21
2.1.9. Indirect Method of Impression for CAD/CAM Systems	22
2.1.10. Advantages of the Digital Workflow	22
2.1.11. Disadvantages of the Digital Workflow	23
2.1.12. Intraoral Scanners for Usage in the Direct Method	24
2.1.13. Methods of Digital Impression	29
2.1.13.1. Digital Impression of Natural Tooth Supported Prosthesis	29
2.1.13.2. Digital Impression of Implant Supported Prosthesis	29
2.1.14. Factors that Influence Digital Implant Impressions	30
2.1.14.1. Intraoral Scanner and Software	30
2.1.14.2. Scan Body	31
2.1.14.3. Scanning Powder Application	32
2.1.14.4. Protocols of Scanning	33
2.1.14.5. Resolution of Image	34
2.1.14.6. Scanned Arc Length and Area	35
2.1.14.7. Artifacts	36
2.1.14.8. Optic Noise	36
2.1.14.9. Experience of the Operator	36
2.1.14.10. Implant Position	36
2.1.14.11. Patient Related Factors	37
2.2. Methods for the Evaluation of Implant Impression Accuracy	37
2.2.1. Reference Scanners	38
2.2.2. Digital Data Evaluation	39

2.2.3. Passive Fit and Outcomes of Non-Passive Fit	40
3. MATERIALS AND METHODS	42
3.1. Reference Model Fabrication	44
3.2. Acquisition of the 3D Reference Models	46
3.3. Taking Digital Impressions with an Intraoral Scanner	47
3.4. Taking Conventional Impressions with Polyvinylsiloxane, Polyether and Polyvinyl Siloxane Ether	49
3.4.1. Conventional Impression with Polyvinylsiloxane	50
3.4.2. Conventional Impression with Polyether	52
3.4.3. Conventional Impression with Polyvinyl Siloxane Ether	53
3.5. Pouring of the Casts of Conventional Impressions	55
3.6. Digitalization of the Models Cast from the Conventional Impression Techniques	55
3.7. Evaluation with Geomagic Control X	56
3.8. Statistical Analysis	62
4. RESULTS	63
5. DISCUSSION	67
6. CONCLUSION	81
7. REFERENCES	82
8. APPENDIX	98
8.1. CURRICULUM VITAE	98

## TABLE LIST

<b>Table 3.1.</b> Test Materials Used in the Study	43
<b>Table 3.2.</b> Devices Used in the Study	44
<b>Table 4.1.</b> Descriptive Data of the Groups	63
<b>Table 4.2.</b> Evaluation of the Impact of Model and Impression Groups on Accuracy	64
<b>Table 4.3.</b> Evaluation of the Accuracy of Model and Impression Groups	65



## FIGURE LIST

<b>Figure 2.1.</b> Materials Used for Splinting Impression Copings	5
<b>Figure 2.2.</b> Types of Impressions	6
<b>Figure 2.3.</b> Digital Dentistry Workflow	13
<b>Figure 2.4.</b> STL File Production by Using an Intraoral Scanner	16
<b>Figure 2.5.</b> Working Principles of Intraoral Scanners	18
<b>Figure 2.6.</b> Determining the Object Distance	18
<b>Figure 2.7.</b> Distal Shadow Phenomenon	20
<b>Figure 2.8.</b> Nature of Light	21
<b>Figure 2.9.</b> 3Shape Wireless and MOVE IOS	25
<b>Figure 2.10.</b> CEREC Omnicam IOS	26
<b>Figure 2.11.</b> EmeraldS Planmeca IOS	26
<b>Figure 2.12.</b> Heron 3Disc IOS	27
<b>Figure 2.13.</b> Primescan Dentsply Sirona IOS	28
<b>Figure 2.14.</b> Element 5D iTero IOS	28
<b>Figure 2.15.</b> Scan Bodies of Different Implant Manufacturers	30
<b>Figure 2.16.</b> Main Parts of a Digital Scan Body	31
<b>Figure 2.17.</b> Scanning Strategies	33
<b>Figure 2.18.</b> Scan Protocols for Different Manufacturers	34
<b>Figure 2.19.</b> Relationship Between Trueness and Precision as Defined by ISO	38
<b>Figure 3.1.</b> The Workflow of the Study	42
<b>Figure 3.2.</b> Reference Models on the Parallelometer	45
<b>Figure 3.3.</b> Finalized Versions of the Reference Models	46
<b>Figure 3.4.</b> Anti-Glare Spray and Scanning with 3Shape 1E Lab Scanner of the Reference Models	47
<b>Figure 3.5.</b> Scanned Virtual Reference Models	47
<b>Figure 3.6.</b> Trios 3 Device in Yeditepe University Faculty of Dentistry	48
<b>Figure 3.7.</b> Scanned Reference Models with Trios 3 Device	49
<b>Figure 3.8.</b> Splinting of the Impression Copings with Pattern Resin	50
<b>Figure 3.9.</b> Application of PVS Tray Adhesive and PVS Impression Material	51
<b>Figure 3.10.</b> Pentamix and Garant Dispenser	51
<b>Figure 3.11.</b> Impression with PVS	52
<b>Figure 3.12.</b> Application of PE Tray Adhesive and PE Impression Material	53

<b>Figure 3.13.</b> Impression with PE	53
<b>Figure 3.14.</b> Application of PVSE Tray Adhesive and PVSE Impression Material	54
<b>Figure 3.15.</b> Impression with PVSE	54
<b>Figure 3.16.</b> Example of a Conventional Impression Cast	55
<b>Figure 3.17.</b> Scanning of the Conventional Impression Models with 3Shape 1E Lab Scanner	56
<b>Figure 3.18.</b> Evaluation of an Angulated Model Impression with Polyvinylsiloxane Using Geomagic Control X	58
<b>Figure 3.19.</b> Evaluation of an Angulated Model Impression with Polyether Using Geomagic Control X	58
<b>Figure 3.20.</b> Evaluation of an Angulated Model Impression with Polyvinyl Siloxane Ether Using Geomagic Control X	59
<b>Figure 3.21.</b> Evaluation of an Angulated Model Impression with Digital Method Using Geomagic Control X	59
<b>Figure 3.22.</b> Evaluation of a Parallel Model Impression with Polyvinylsiloxane Using Geomagic Control X	60
<b>Figure 3.23.</b> Evaluation of a Parallel Model Impression with Polyether Using Geomagic Control X	60
<b>Figure 3.24.</b> Evaluation of a Parallel Model Impression with Polyvinyl Siloxane Ether Using Geomagic Control X	61
<b>Figure 3.25.</b> Evaluation of a Parallel Model Impression with Digital Method Using Geomagic Control X	61
<b>Figure 4.1.</b> Comparison of the Impact of Model and Impression Groups on Accuracy	65

## LIST OF SYMBOLS AND ABBREVIATIONS

°	Degrees
μ	Micron
3D	Three Dimensional
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CBCT	Cone Beam Computerized Tomography
CCD	Charge Coupled Device
IOS	Intraoral Scanning
Ncm	Newton Centimeter
PE	Polyether
PEEK	Polyetheretherketon
POI	Points of Interest
PSD	Position Sensitive Device
PVS	Polyvinylsiloxane
PVSE	Polyvinyl Siloxane Ether
RMS	Root Mean Square
STL	Standard Triangle Language
US	Ultrasound
USA	United States of America

## ABSTRACT

**Çopuroğlu, A. (2024). Comparison of the accuracy of digital and conventional impression techniques in multiple implants with different angulations. Yeditepe University, Institute of Health Sciences, Department of Prosthodontics, Ph.D, Thesis. Istanbul.** The purpose of this study is to evaluate the effect of digital impression technique and conventional impression technique with different materials on the accuracy of impression in fully edentulous jaws with multiple implants placed at various angles. The current study evaluated two different fully edentulous upper jaw master models in which four internally connected implants were placed parallelly and angled to each other. In the first master model, four implants were positioned at a 90° angle to the occlusal plane and parallel to each other. In the second master model, two implants were placed in the anterior region in the canine areas at a 90° angle to the occlusal plane and parallel to each other, while the other two implants were placed in the posterior region at a 30° distal angle according to the all-on-4 protocol. Stock open trays with window space corresponding to the implant site were used for the conventional groups. Impressions were taken from the models using three different conventional impression materials; polyvinylsiloxane (PVS), polyether (PE), polyvinyl siloxane ether (PVSE), and digital impression method (3Shape TRIOS 3). As the sample size for each group was determined to be 10 based on the results of the power analysis, the impression process was repeated 10 times for each group. Cast models were produced from the conventional impressions, and all samples were scanned with an extraoral scanner (3Shape Lab Scanner 1E) and stored as STL files. The STL files of the obtained 8 groups were evaluated for accuracy using the Geomagic Control X program. In the evaluation of the findings of the study, IBM SPSS Statistics 22 software was used for statistical analysis. The normal distribution of parameters was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests, and it was determined that the parameters were normally distributed. For assessing the amount of deviation in the study data, a two-way ANOVA test was used, along with post hoc Tukey test. Significance was evaluated at  $p < 0.05$  level. In the parallel model; the deviation amount of the digital impression group was significantly higher than the PE group ( $p:0.016$ ;  $p < 0.05$ ), and there was no statistically significant difference among the other groups ( $p > 0.05$ ). In the angulated model; the deviation amount of PE group was significantly lower than the PVSE group ( $p:0.007$ ;  $p < 0.05$ ), and the digital impression group ( $p:0.016$ ;  $p < 0.05$ ); and there was no statistically significant difference among the

other groups ( $p>0.05$ ). When parallel model and angulated model was compared, the deviation amount increased in each group, and statistically significant results were found in PVS, PE, and digital impression groups ( $p<0.05$ ). The angulation of implants had a negative effect on the accuracy of the impression. Polyether impression material provided more accurate results in both parallel and angulated cases.

**Keywords:** impression accuracy, parallel implant, angulated implant, polyvinylsiloxane, polyether, polyvinyl siloxane ether



## ÖZET

**Çopuroğlu, A. (2024). Farklı açılarda yerleştirilmiş çoklu implantlarda dijital ve konvansiyonel ölçü tekniklerinin doğruluğunun karşılaştırılması. Yeditepe Üniversitesi, Sağlık Bilimleri Enstitüsü, Protetik Diş Tedavisi Anabilim Dalı, Doktora Tezi, İstanbul.** Bu çalışmanın amacı; tam dişsizlik vakalarında çok sayıda ve farklı açılarda yerleştirilmiş implantlarda, dijital ölçü tekniğinin ve farklı konvansiyonel ölçü materyallerinin, ölçünün doğruluğu üzerine olan etkilerini karşılaştırmaktır. Mevcut çalışma, birbirine paralel ve farklı açılarda yerleştirilmiş 4 internal bağlantılı implantın bulunduğu 2 farklı tamamen dişsiz üst çene ana modelini değerlendirmiştir. İlk ana modelde, 4 implant oklüzyon düzlemine 90° açıyla ve birbirine paralel olarak konumlandırılmıştır. İkinci ana modelde, 2 implant anteriorda kanin dışı bölgelerinde oklüzyon düzlemine 90° açıyla ve birbirine paralel olarak yerleştirilmiş, diğer 2 implant ise posteriorda all-on-4 protokolüne göre 30° distal açıyla konumlandırılmıştır. Konvansiyonel ölçü grupları için implant bölgesine karşılık gelen pencere boşluğuna sahip prefabrike açık ölçü kaşıkları kullanılmıştır. Ölçüler, 3 farklı konvansiyonel ölçü materyali; polivinilsiloksan (PVS), polieter (PE), polivinil siloksan eter (PVSE) ve dijital ölçü yöntemi (3Shape TRIOS 3) kullanılarak modellerden alınmıştır. Her grup için örnek sayısı, güç analizi sonuçlarına dayanarak 10 olarak belirlendiği için ölçü süreci her grup için 10 kez tekrarlanmıştır. Alçı modelleri, konvansiyonel ölçülerden üretilmiştir ve tüm örnekler, bir ekstroral tarayıcıyla (3Shape Lab Scanner 1E) taranıp STL dosyaları olarak saklanmıştır. Elde edilen 8 grubun STL dosyaları, doğruluk açısından Geomagic Control X programı kullanılarak değerlendirilmiştir. Çalışmada elde edilen bulgular değerlendirilirken, istatistiksel analizler için IBM SPSS Statistics 22 programı kullanılmıştır. Parametrelerin normal dağılıma uygunluğu Kolmogorov-Smirnov ve Shapiro Wilks testleri ile değerlendirilmiş ve parametrelerin normal dağılıma uygun olduğu saptanmıştır. Çalışma verileri değerlendirilirken sapma miktarının değerlendirilmesinde iki yönlü Anova testi (2-way ANOVA Test), post hoc Tukey testi kullanılmıştır. Anlamlılık  $p < 0.05$  düzeyinde değerlendirilmiştir. Paralel modelde; dijital ölçü grubunun sapma miktarı PE grubundan anlamlı düzeyde yüksek bulunmuştur ( $p:0.016$ ;  $p < 0.05$ ), diğer gruplar arasında istatistiksel olarak anlamlı bir fark bulunmamıştır ( $p > 0.05$ ). Açılı modelde; PE grubunun sapma miktarı PVSE grubundan ( $p:0.007$ ;  $p < 0.05$ ) ve dijital ölçü grubundan ( $p:0.016$ ;  $p < 0.05$ ) anlamlı düzeyde düşük bulunmuştur; diğer gruplar arasında istatistiksel olarak anlamlı bir fark bulunmamıştır

( $p>0.05$ ). Paralel model ve açılı model karşılaştırıldığında, her grupta sapma miktarının arttığı ve PVS, PE ve dijital ölçü gruplarında istatistiksel olarak anlamlı sonuçlar bulunduğu görülmüştür ( $p<0.05$ ). İmplantların açısı, ölçünün doğruluğu üzerinde negatif bir etkiye sahiptir. Polieter ölçü materyali, hem paralel hem de açılı implant vakalarında daha doğru sonuçlar verir.

**Anahtar Kelimeler:** : Ölçü doğruluğu, paralel implant, açılı implant, polivinilsiloksan, polieter, polivinil siloksan eter



## 1. INTRODUCTION AND PURPOSE

Implants are the treatment of choice for the rehabilitation of missing teeth in terms of esthetics and function. To provide the patients with excellent functional and esthetical results, impression is a very important stage in the production of the implant supported restorations.

Impression is defined as “a negative copy of the surface of any object” according to the Glossary of Prosthodontic Terms.<sup>1</sup> Impression of tooth supported restorations is described 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”.<sup>2</sup> If an implant supported restoration is to be made using implants and abutments, the impression is defined as 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”.<sup>2</sup>

The accuracy of the impression is the key in the production of a compatible prosthesis. The fit of the prosthesis is the most important factor that affects the quality of the restoration. The impression accuracy has a direct effect on the fit of the prosthesis thus it is critical in terms of the longevity of the prosthesis. The chosen impression material and technique have an effect on the success of the restoration as well.<sup>3</sup>

Since implant-supported fixed prosthesis have become more prevalent, the accuracy of the impression have also become very important. For an implant-supported restoration to be successful in long-term, the passive fit of the restoration is critical. Passive fit is observed when there is no static load on the prosthetic system and the surrounding bone tissue after the manufacture of the restoration on abutments. In other words, passive fit can be defined as the lack of tension between the infrastructure and the abutment.<sup>4</sup>

To obtain a passive fit, the implant or teeth position in the oral cavity must be accurately transferred to the model. In other words, a correct impression must be acquired. Appropriate impression technique and correct impression material must be chosen to acquire a meticulous recording of the relationship of teeth/abutment and the neighboring structures. Errors that are made in the impression stage can have a negative effect on the

following laboratory stages. Moreover, minor mismatches can result in stress accumulation on and around the implant.<sup>5</sup>

Several impression materials have been developed to increase the accuracy of impressions that are taken for prosthetic restorations. Polyether and polyvinylsiloxane impression materials are widely used materials of choice for the conventional impression methods due to their superior properties.<sup>4</sup> Polyvinyl siloxane ether is a relatively new material introduced to the market that combined the favorable properties of polyether and polyvinylsiloxane.<sup>4,6</sup> Its effects on accuracy of implant-supported restorations have not been thoroughly examined.

The digital age of dentistry have started with the development of intraoral scanners for the acquisition of digital impressions. When these scanners were first manufactured, their use was limited to cases such as single crowns.<sup>5</sup> Today, studies show that implant-supported restorations of edentulous patients can be produced by using intraoral scanners.<sup>7,8</sup> To the contrary, accuracy of intraoral scanners and the passive fit of restorations manufactured from these scans is currently the subject of research.<sup>8,9</sup>

Two different methods can be used to assess the accuracy of impressions. The first method is to fabricate the fixed restoration on the master model and evaluate its fit. The second method is to compare the 3D model of the cast model made from the impression and the 3D model of the master model. Appropriate softwares can be used to analyze the three-dimensional discrepancies between two model's data by superimposition.<sup>10</sup>

The aim of this thesis is to evaluate and compare the accuracy of digital and conventional impression techniques with different materials in multiple implants with different angulations.

The first null hypothesis is that there is no statistically significant difference between conventional impressions taken with polyvinylsiloxane, polyether, polyvinyl siloxane ether and digital impressions. The second null hypothesis is that there is no statistically significant difference between impressions of parallel and angulated implants.

## **2. GENERAL INFORMATION**

### **2.1 Impression Techniques for Implant Supported Prosthesis**

The capture of the prepared area, inside of the mouth or other regions by using different application techniques and materials refers to the impression taking procedure.<sup>1</sup> If an impression of tooth-supported prosthesis is to be obtained then the process is called obtaining the shapes and relationships of teeth, hard and soft tissues in the oral cavity or obtaining negative copies of the regions of the mouth. If an impression of the implant-supported prosthesis is to be obtained, then the process is called the transfer of the position of the implant in three dimensions and the relationship between soft and hard tissues to the dental laboratory<sup>2</sup>.

The goal is to obtain impressions which are accurate copies of the actual impression field, easy, fast, and convenient for both the doctor and the patient. Digital or conventional methods can be used for the acquisition of impressions. Currently, digital impressions have become more popular. However, conventional impression methods are also used broadly throughout the world for the impression of implant supported restorations. In the conventional method, the dentist places the impression tray, which holds the impression material, into the patient's mouth, and after the impression material is set, removes the impression tray from the patient's mouth. Even though the digital impression method is commonly used as new scan bodies, scanners and ti-base sets are developed, for the full arch impressions more study data is required for definitive accuracy results.<sup>11</sup>

For clinical success and to have a good prognosis for the implant supported restoration, impression must be without any fault, and it must provide a superstructure which has a passive fit.<sup>12</sup>

#### **2.1.1 Conventional Methods for the Impression of Implant Supported Prosthesis**

For the manufacture of implant supported restorations, one-stage impression techniques can only be used. The impression can be taken either with direct or indirect techniques.<sup>13</sup>

According to studies, the most frequently used materials are polyvinylsiloxane (PVS), and polyether (PE).<sup>14</sup> Once the impression is removed from the mouth, it must maintain its rigidity so that the impression analogs are not displaced. Polyether's rigidity is very high; thus, it is commonly used for the impression of implant supported prosthesis.<sup>15</sup> Hardness value of polyether is relatively higher when compared with PVS. As a result, permanent deformation is lower in impressions taken with polyether. On the other hand, PVS has lower elastic modulus when compared to polyether, thus it is easier to remove from the patient's mouth once the impression is set.<sup>15,16</sup>

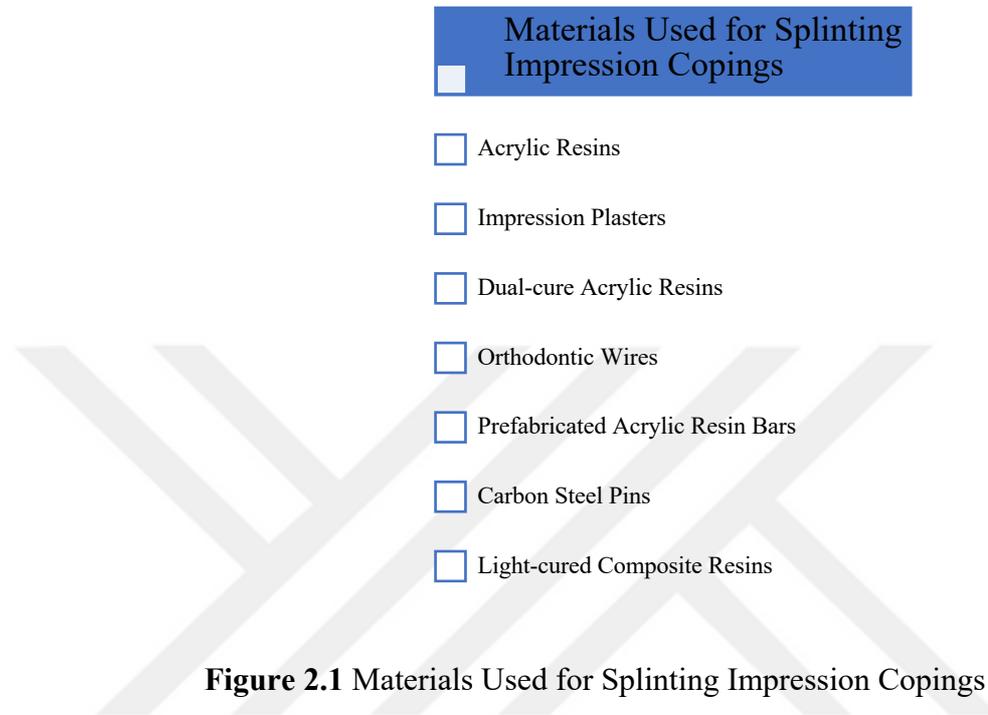
#### **2.1.1.1 Indirect Method (Closed Tray)**

In cases with 3 or less implants which are somewhat parallel to each other, closed tray technique can be used. Individual tray manufacture is not needed. According to the height of the closed tray, tapered copings and analogs are used in this method. Heavy body impression material is poured into the tray and injected around the impression copings in the mouth. Once the impression is set and removed from the mouth, the copings remain intraorally. Afterwards, the copings are withdrawn from the implants, and screwed to the implant replicas to be placed in their appropriate places in the impression. Lastly, the completed impression set is sent to the dental laboratory.<sup>13,17</sup>

#### **2.1.1.2 Direct Method (Open Tray)**

When non-parallel implants or bilateral several implants are present, direct method for impression is preferred. Individual custom trays must be manufactured for this method. The custom tray must have appropriate holes so that the coronal part of the impression copings can be exposed in the mouth. Once the impression is set, the copings are unscrewed and taken out with the impression. Then the implant analogs are connected to the copings. In this method, the impression coping stays within the impression material and the dentist does not place the coping back after the impression is set, so less instances of misfit or other margins of error is expected. On the other hand, there are several disadvantages of this method such as the rotational movement of the impression coping while connecting to the implant analog, and the misfit of components due to blind attachment of implant analog to impression coping. To overcome these disadvantages, the impression copings are splinted to each other inside the mouth. Many materials can be used to splint the copings such as acrylic resin, orthodontic wires and light-cured

composite resin. The material which is most preferred is the auto polymerizing acrylic resin. As a result of splinting, the possible movements of impression components are prevented since the splinting is made with a rigid material.<sup>18,19</sup>



**Figure 2.1** Materials Used for Splinting Impression Copings<sup>20–23</sup>

When the patient has gag reflex, restricted mouth opening, or if the implants are placed in a very difficult position, it is recommended to use the closed tray method.<sup>14,24–</sup>

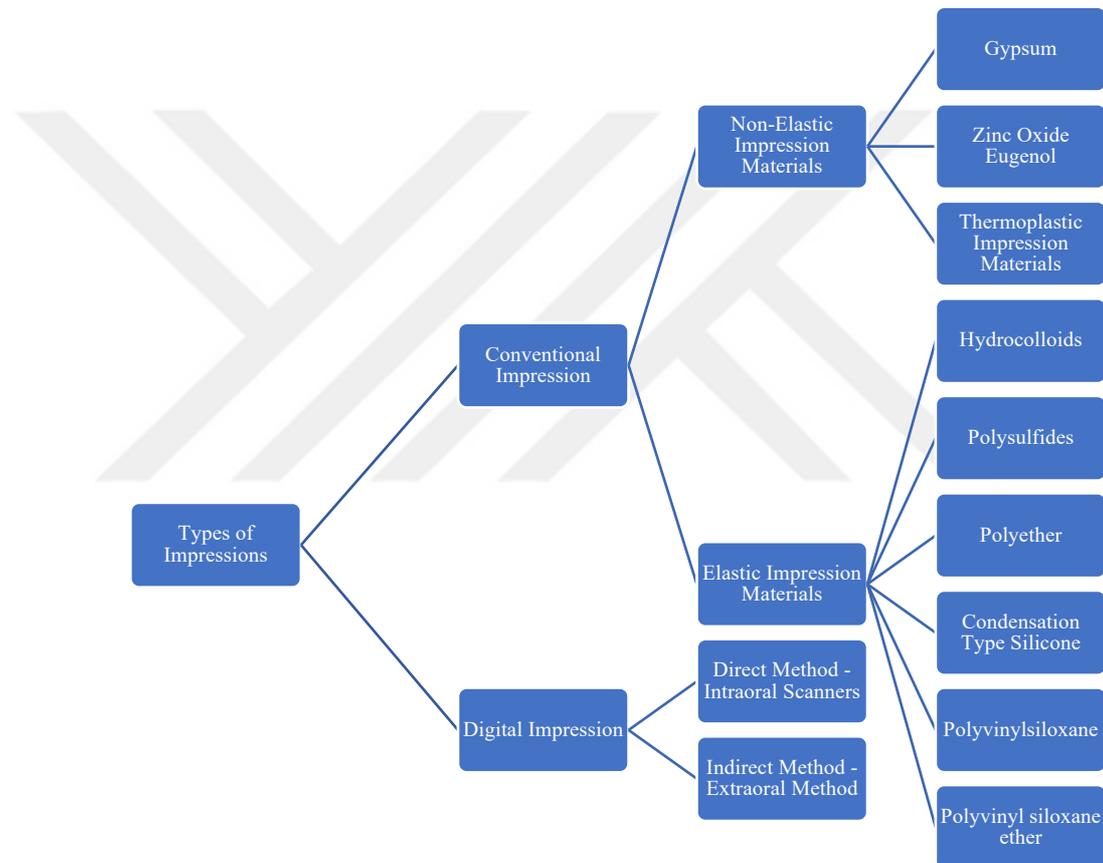
26

### **2.1.1.3 Snap-on Method (Press-fit)**

This method is used by some implant companies in which a plastic impression cap is placed on the impression copings for the closed tray impression technique. The usage of these caps are mostly preferred in cases that have implants with various angles or implants which are very close to each other. The plastic cap is placed onto the impression coping with finger pressure, and it is very user-friendly, time saving, and comfortable for the patient. The disadvantage of this technique is that micromovements can occur since the plastic cap stretches while the impression is removed from the mouth. Moreover, if the implants are very close to each other and the plastic cap cannot be properly placed, loss of retention may occur, and impression may have to be taken several times. In such cases, direct impression technique is recommended.<sup>17,19</sup>

## 2.1.2 Conventional Impression Materials Used for Implant Supported Prosthesis

For an implant to be successful in the long term, the impression must be obtained accurately. Condensation type silicone and polysulfide-based materials were used in the past to obtain the impression of implant supported restorations. Currently, it is recommended to use polyvinylsiloxane and polyether based impression materials.<sup>11</sup>



**Figure 2.2** Types of Impressions

### **2.1.2.1 Polysulfide**

Polysulfide impression material contains two tubes which are the catalyst and the base. It has been used due to its low cost and ensuring high accuracy. According to its flowability, different types are available in the market. The base contains polysulfide, filler and plasticizer. The catalyst contains reaction initiator, which is lead dioxide, copper and organic dioxides, sulfur (modifier), and form formers (reactive oils and dibutyl phthalate). Polysulfides have long working time, high capacity to stretch, high tear strength and well-executed surface details. The difficulty in its usage is due to its low viscosity. Moreover, the patients can be annoyed because of its bad odor.<sup>3,27</sup>

### **2.1.2.2 Polyether**

Polyether impression material was first introduced to the market in the late 1960s. It comes in two pastes and has different forms according to its viscosity which are low, medium, and high. Polyether, colloidal silica, and plasticizer makes up the base part. Thinners, fillers and aromatic sulfamic acid ester makes up the catalyst part. When the base and catalyst is mixed, addition type reaction occurs, and no by-products are formed. It has very low stretching ability. After polymerization, it turns into a very hard structure. As a result, tears may occur in the undercut areas when the impression is removed from the oral cavity. It has excellent dimensional stability. When it is stored in dry conditions, it can maintain its form up to a week. Since it has a hydrophilic structure, it obtains high details of the surface, and it is easier to cast the model in the laboratory.<sup>27-29</sup>

### **2.1.2.3 Condensation Type Silicone (Type-C Silicone)**

Type-C silicone is mostly used as the impression material of choice for fixed prosthesis. According to its viscosity it comes in four different forms: low, medium, high and very high. Different catalyst systems can be found which are putty-putty or putty-liquid. The base part contains dimethyl siloxane polymer, fillers and crosslinkers. The catalyst part contains thinners and organic metal esters. The name condensation type silicone comes from the fact that it polymerizes with a condensation reaction. As a result of this reaction, alcohol is formed as a by-product. The dimensional stability of c-type silicones is inadequate because the residual alcohol evaporates after impression taking and this evaporation causes shrinkage. Consequently, once the impression is set and

removed from the mouth, plaster must be poured out as soon as possible. Condensation type silicone is a hydrophobic material; thus the impression surface must be dried out excessively. Moreover, the material has limited ability to present surface details.<sup>3,27</sup>

#### **2.1.2.4 Polyvinylsiloxane (Type-A Silicone)**

Additional type silicones have been widely used since the 1990s. Even though type-a silicones are costly, they are mostly favored because of their dimensional stability, outstanding physical properties, and ease of use. The base part contains polymethyl hydro siloxane which is made up of inert fillers and terminal silane hydrogen groups. The activator part is made up of dimethyl siloxane polymer, terminal vinyl groups, and chloroplatinic acid. Addition reaction causes the polymerization of these groups. No residual product is formed in this reaction. However, additional hydrogen groups are formed. Once the impression is set, the hydrogen is released. The material's exemplary dimensional stability comes from the fact that no by-products are formed during the polymerization process. The impression maintains its stability up to a week and several casts can be made with one impression. By the addition of surfactants, the additional type silicones have been made hydrophilic. According to studies, it was determined that the latex gloves and rubber covers contained sulfur and sulfur caused the degradation of the platinum that the activator contains. Thus, the additional polymerization reaction is inhibited. This unwanted reaction can be avoided with the use of nitrile or vinyl gloves. Even though it has disadvantages, additional type silicone is the most used impression material for fixed restorations because of their remarkable physical characteristics.<sup>3,27</sup>

#### **2.1.2.5 Polyvinyl Siloxane Ether**

Polyvinyl siloxane ether is the latest elastic impression material, and it was introduced to market in the late 2000s. This material was produced by the combination of the characteristics of polyether and polyvinylsiloxane. Even though encouraging results were expected since the material had the physical characteristics such as elasticity of polyvinylsiloxane and the hydrophilicity of polyether, the material had problems with moisture control. Moreover, subgingival area impression was also problematic. As a result, more research must be conducted to evaluate the material.<sup>6,30</sup>

## **2.1.3 Abutment Level and Implant Level Impression**

### **2.1.3.1 Abutment Level Impression**

The abutment is chosen according to the angle, diameter and length of the implant then torqued. Afterwards, the impression is taken with plastic caps very much alike the snap-on technique. In this method, the correct positioning of the plastic cap and the sensitivity of the sense of touch is crucial.<sup>26,31</sup>

### **2.1.3.2 Implant Level Impression**

Once the healing caps are detached, impression copings are connected to the implant, and the impression is taken by using the direct or indirect technique. Implant level impressions have several advantages such as: simple production of temporary restorations, good esthetic outcomes, easier selection of abutments on the cast.<sup>32,33</sup>

## **2.1.4 Factors that Influence the Conventional Impression of Implant Supported Prosthesis**

### **2.1.4.1 Impression Technique**

There are different methods that can be used for the impression of multi implant cases such as direct, indirect, and snap-on technique. However, the best method is not proven yet. For each patient, the preferred technique is usually the one which takes the shortest duration, easier to perform, causes less discomfort for the patient and renders the highest accuracy.<sup>18,34</sup>

### **2.1.4.2 Number of Implants and their Angulations**

Implant angulation and the number of implants also influences the accuracy of the impression. When the implant angulation is greater than 20 degrees for both completely and partially edentulous cases, the impression accuracy is affected negatively due to the increase of distortion.<sup>35</sup> In cases which have more than 3 implants, better accuracy results are obtained by using the direct method.<sup>26</sup>

### **2.1.4.3 Implant Connection Levels (Implant Level and Abutment Level)**

Implant level impression is taken by screwing the impression coping to the implant. Once the impression material is set and the tray is taken out of the mouth, the abutment is selected on the model and the superstructure production begins. Abutment level impression is taken by connecting the proper abutment with the implant and taking the impression afterwards. The selected abutment is not removed from the mouth after the impression is taken.<sup>36</sup> Implant connection level's effect on the accuracy of impression still does not have enough evidence to reach a conclusion.

### **2.1.4.4 Type of Impression Coping**

To obtain better accuracy results, impression copings were modified using several techniques such as applying an adhesive layer and roughening the outer surface of the coping. While there are several studies that investigated these copings, there is not enough evidence to reach a conclusion about which is the best modification for the most accurate impression.<sup>37,38</sup>

### **2.1.4.5 Type of Implant Connection**

The stability of the implant-prosthesis interface highly depends on the implant-abutment connection's shape and geometry. There are several types of implant-abutment connections such as external hexagon, internal hexagon, and taper joints.<sup>39</sup>

#### **2.1.4.5.A. External Connection**

External connection is “a connection feature that extends superior to the coronal portion of the implant”.<sup>40</sup> It yields an anti-rotation mechanism. It is easier to retrieve, and it is compatible with different systems.<sup>35</sup> On the other hand, external connection has several disadvantages such as micro-movements and higher rotation center that causes lower resistance against lateral and rotational movements. Moreover, the micro gap between the connection and implant can lead to bone resorption. Since the external hex also has a limited height when compared with internal connection, it can cause a larger degree of divergence during impression taking process.<sup>41</sup>

#### **2.1.4.5.B. Internal Connection**

Internal connection is “a connection feature that extends inferior to the coronal portion of the implant and is located inside the implant body”.<sup>40</sup> Internal connection is a simple and reliable system, and it is suitable for one stage implant installation. Its connection area is wider, so it has higher stability and anti-rotation which makes it applicable for single tooth restorations. Since it has a lower center of rotation, it renders better resistance against lateral loads. It also has higher stress distribution. On the other hand, internal connection systems have several disadvantages such as being prone to fractures due to thinner wall of the fixture at the connection junction and it is harder to adjust in cases of angulated implants.<sup>42,43</sup>

#### **2.1.4.5.C. Conical Connection**

True morse taper is “an abutment “cone within a cone” creating a seal between the implant and the abutment without the need for a retaining screw”. Cone screw is the “internal, tapered, self-locking connection utilizing the self-locking principles of a morse taper but with a retaining screw connecting the abutment to the implant”. Conical connection’s main advantage is its better sealing capacity in closing the micro gap which is on top of an internal hex connection.<sup>40</sup>

#### **2.1.4.6 Implant Placement Depth**

In cases that have available bone and better esthetic outcomes are preferred, dental implants can be placed more subgingivally. As a result, during impression taking the impression coping must also be placed more subgingivally. Thus, less area of the impression coping is exposed to the impression material. Subsequently, this situation can affect the stability of the coping and impressions’ accuracy.<sup>44</sup>

#### **2.1.4.7 Cast Pouring Techniques**

The conventional way is to mix the type IV die stone which has low expansion (0.09%) in the proper machine and according to the manufacturer instructions and pour into the impression. Another method is the double pouring technique. According to 2 clinical and a few in vitro studies, double pouring technique yields better results. In the double pouring technique, after the impression analogs are screwed to the coping type IV

die stone is mixed. The stone is mixed manually with distilled water for 15 seconds so that water is incorporated properly. Afterwards, stone is mixed under vacuum and poured until the ½ of the analogs is visible. All of the stone mixtures must be vibrated before and after it is poured. After 30 minutes passes, a second batch of vacuum-mixed die stone is poured. According to the studies, this technique minimizes the stone's volumetric expansion thus leading to better accuracy of the die casts.<sup>18,45-47</sup>

#### **2.1.4.8 Machining Tolerance**

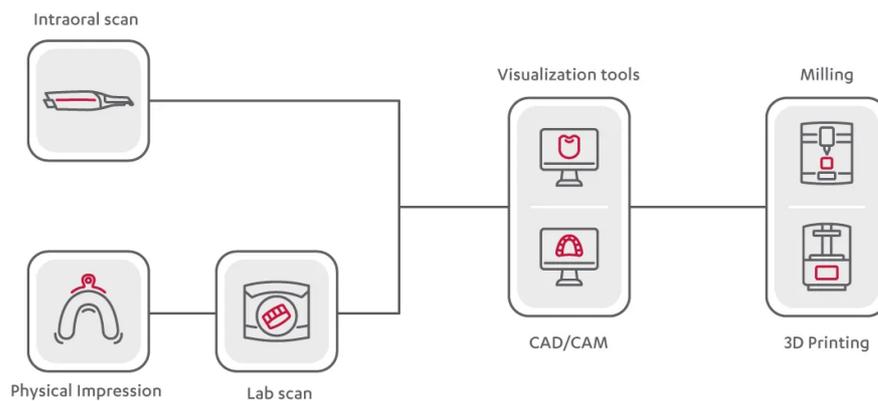
The paired prosthetic components can be displaced rotationally while they are screwed onto their respective parts. The clinician cannot control this rotational displacement and it lies within the range of inherent machining tolerance. Different implant systems have different machining tolerances and its effect on the accuracy of impression needs more investigation.<sup>48,49</sup>

#### **2.1.5 Digital Impression Technique**

When the clinician follows the ideal instructions, conventional impression techniques yield accurate outcomes in the production of prosthetic restorations. To reduce the risk that occur during the impression process and to the decrease the number prosthetic restoration manufacturing stages, CAD/CAM systems have been developed. As CAD/CAM systems have developed very quickly with the progress of technology, these systems allow the clinician to acquire the impression from the patient's mouth directly, and then the models can be transferred digitally. Since it is user-friendly and fast, digital dentistry have become quite popular in the current clinical applications. Notably within the last decade, different companies developed intraoral scanners and put them on the market.<sup>50</sup>

In 1997 in the United States of America (USA), Bruce Altschulker developed a computer with optical readers that visualized intraoral tissues. Since the 1980's, CAD/CAM systems related to dentistry have developed rapidly. In the year 1984, Francois Duret refined the Duret system in which single unit restorations were manufactured. In 1988, Cerec systems were used for the first dental CAD/CAM application by Werner Mörmann and Marco Brandestini. This system was beneficial in terms of expense and applicability.<sup>51,52</sup>

CAD/CAM systems have a simple working principle that is made up of three stages which are digitalization, design, and production. Digitalization's main goal is to obtain data from inside the mouth using intraoral scanners and transfer the data to the digital media. In the design stage, the restoration design is prepared digitally on the obtained 3D models (CAD). Lastly, in the production phase the restorations that were designed in the previous stage are manufactured.<sup>50</sup>



**Figure 2.3** Digital Dentistry Workflow <sup>53</sup>

### **2.1.6 CAD/CAM Systems and their Functional Elements**

CAD/CAM systems of dentistry are made of three functional elements which are optical scanner, software program and the fabrication element.<sup>54</sup>

#### **2.1.6.1 Design Software Program (CAD)**

Specialized softwares are used to create restoration designs on the digital models which are acquired from the patient's mouth. Different softwares are available to create these restoration designs. The user can make adjustments on the restorations that are designed by the software in automated systems. Once the designing is concluded, the program converts the models to series of commands. Each software is unique to each CAD/CAM system, and they can't be interchanged between the other software.<sup>54</sup>

### **2.1.6.2 Fabrication (CAM)**

CAM consists of the computer-controlled production of the designed restoration. Subtractive method, additive method, or their combination can be used in this phase. In the early CAD/CAM systems, prefabricated blocks were used with milling systems that contained diamond burrs or disks to manufacture the restoration. This method is called the subtraction method since the prefabricated blocks are subtracted to obtain the designed restoration shape. Even though subtraction is an effective method, during the process approximately 90% of the block material is wasted.<sup>54,55</sup>

Additive method was developed as an alternative to the subtraction method. In this method, the systems produce the restoration by adding “rapid free-form fabrication” such as rapid prototyping. For the manufacture of metal or ceramic restorations, selective laser sintering is one of the methods that use the additive approach. This method uses a series of actions which are quite like the cutting processes of the existing CAD/CAM systems. Nevertheless, rather than cutting during the process sequence, the material in the metal or ceramic powder pool is continuously sintered to manufacture the restoration. Therefore, no material is wasted in the production. Another additive system that is used is stereolithography. In this system, mostly surgical guides, occlusal splints and working models are produced. Other systems such as Procera (Nobel Biocare, Goteborg, Sweden) operates with the combination of the addition and subtraction methods.<sup>54,55</sup>

### **2.1.7 Digital Data Acquisition by Using CAD/CAM Systems**

Touch pins, laser distance meters, linear laser beam scanners that contain a charge coupled device (CCD) camera are the possible machinery that can be used for the existing CAD/CAM systems. Intraoral tissues, impressions and models can be scanned. It takes longer to scan the models if a probe is used since the probe must contact the surface of scan area. The laser distance meter is faster and more economic. However, it's sensitivity diminishes because it detects the rays which are reflected from the beam that position sensitive device (PSD) sensor sends. As a results, it is very difficult to scan corners and sharp edges. Sensitivity is also affected by the resolution of the CCD camera. Surfaces that have undercuts cannot be scanned by any of these methods.<sup>50,56</sup>

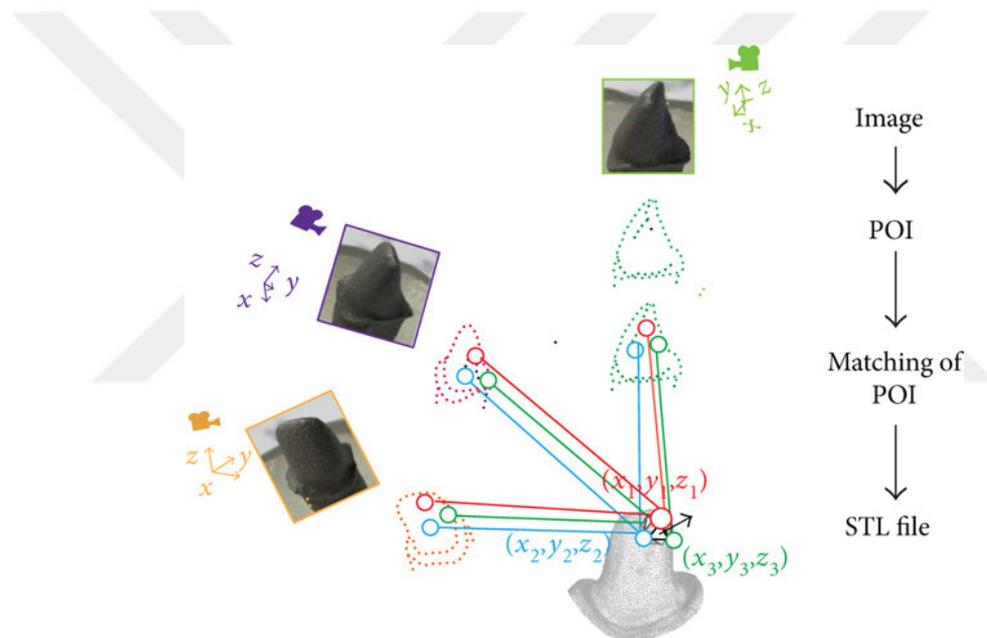
### **2.1.8 Direct Methods of Impression for the CAD/CAM Systems**

In dentistry, 2 kinds of scanners can be used in contact (tactile) and non-contact (non-touch) mode. Contact systems prepare the visual software with the data obtained by the contact of the scanner tip and the object. Non-touch scanners can be obtained in active and passive forms. Passive form non-touch scanners work by detecting objects because of the radiation they emit onto the object. Therefore, these types of scanners are not preferred in dentistry. Mostly active form scanners are used in the dental sector. These touchless 3D scanners, emit different types of radiation; which are light, ultrasound (US) and X-Rays and apprehend the light that the object reflects.<sup>57,58</sup>

Once the digital impression is acquired, surface configuration is completed by using the point cloud captured on the surface of the scanned object. This process is enforced by the algorithm of the software. This algorithm is specifically developed for the intraoral scanner by sorting, organizing, and combining the point clouds into a single image. As a result, the scanned object 3D model is acquired.<sup>59,60</sup>

The software can carry out the surface processing algorithm with high precision if high density of point clouds can be acquired from the scanned surface. As a result, the obtained 3D digital model can be very similar to the scanned object. The software reconstructs surfaces that have insufficient point clouds. The insufficiency occurs as a result of insufficient scanning. The reconstruction that the software makes can be quite different from the actual region thus dimensional variations may occur in terms of size.<sup>61,62</sup>

The digital model is defined in a Standard Triangle Language (STL) file. The STL file size can be different according to different scans made with the same system and according to different intraoral scanning systems. The STL format is mostly used in industrial sector in which the format is based on the triangulation of surfaces by the virtue of triangles made by three points and a surface. To document translucency, color, and other features of dental tissues, other formats have been developed such as Polygon File Format and PLY files. In any case that uses the intraoral scanners, the software has to assemble each and every image or video after points of interest (POI) recognition in all cameras. Every point's first two coordinates (x,y) are evaluated on the image. Afterwards, the third coordinate (z) is calculated according to the space between the object and the camera.<sup>63</sup>



**Figure 2.4** STL File Production by Using an Intraoral Scanner<sup>63</sup>

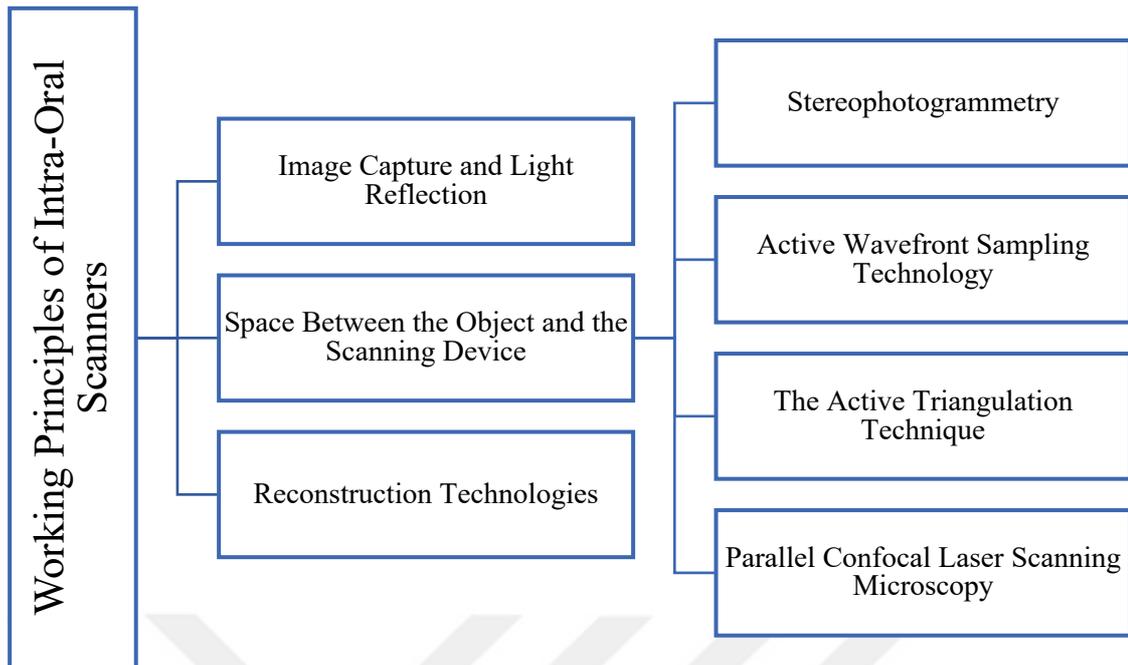
Present intraoral scanners cannot acquire the 3D model of the whole dental arch with a single imaging. Subsequently, intraoral tissues can be digitalized by the acquisition of different images and their combinations made with superimposition. Intraoral scanners can be divided into two groups according to the method used to acquire the images. The first group is the scanners that obtain digital photographs, incorporate them, and make a series of photographs. The second group is the scanners that acquire the images by the digital video technique.<sup>64,65</sup>

Beams of structured light or laser is sent onto the surface of object to be scanned by the intraoral scanners. The beams are imposed to deformation on the scanned surfaces, and the scanner uses two or more cameras to detect these deformations. 3D coordinate calculations are made by the processors and software. Afterwards, the software makes the 3D reconstruction of the scanned surface by the data of point clouds and meshes. Thousands of points are detected every second by the software, then the obtained images are combined to produce a 3D model. It should be noted that the greatest dimensional discrepancies that happen in digital dentistry occur because of the combination of the images.<sup>66,67</sup>

Intraoral scanner developed by different companies have different working protocols like triangulation, wave front sampling, confocal microscopy, interferometry, laser, structured light, and video. As a result of having different working protocols, different scanners produce images that are different in terms of accuracy.<sup>61</sup>

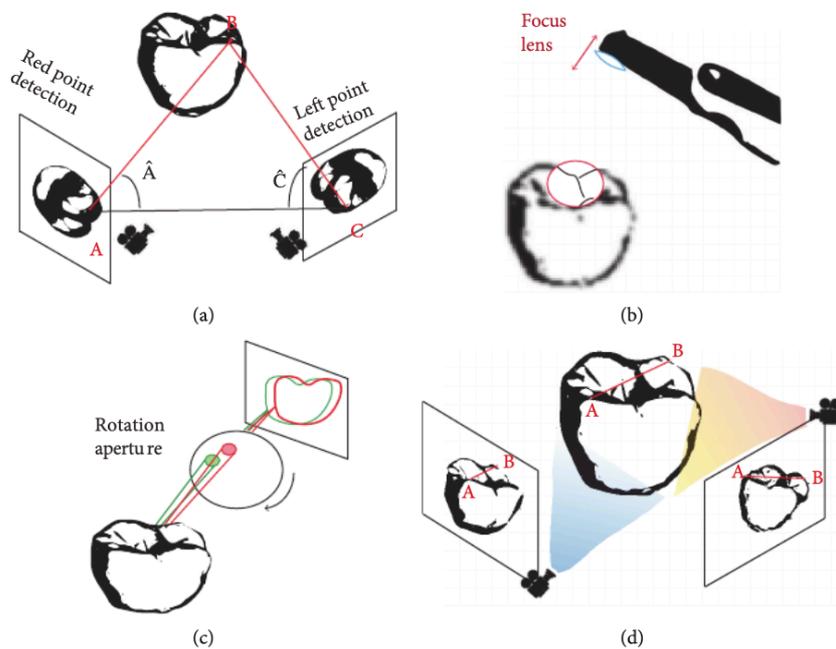
Scanned object surfaces can be visualized with various intensities according to the application of the intraoral scanner by the operator. When the same surface is scanned by various operators or at different instances by the same operator, different intensities can be acquired. As a result, inaccurate surfaces may be acquired in the 3D models.<sup>66</sup>

Other than video recording and photography, intraoral scanners can be classified by their operating principles and image digitalization algorithms.<sup>65</sup>



**Figure 2.5** Working Principles of Intraoral Scanners <sup>63</sup>

### 2.1.8.1 The Space Between the Object and the Scanning Device



**Figure 2.6** Determining the Object Distance: (a) Triangulation. (b) Confocal. (c) Active Wavefront Sampling Technology. (d) Stereophotogrammetry <sup>63</sup>

### **2.1.8.1.A. Stereophotogrammetry**

Stereophotogrammetry completes an algorithmic analysis of images and calculates all coordinates (x,y, and z). It mostly depends on software and passive light projection instead of hardware and active projection. It's camera is comparably smaller. It is easier to handle by the operator, and it's production costs are lower.<sup>63</sup>

### **2.1.8.1.B. Active Wavefront Sampling Technology**

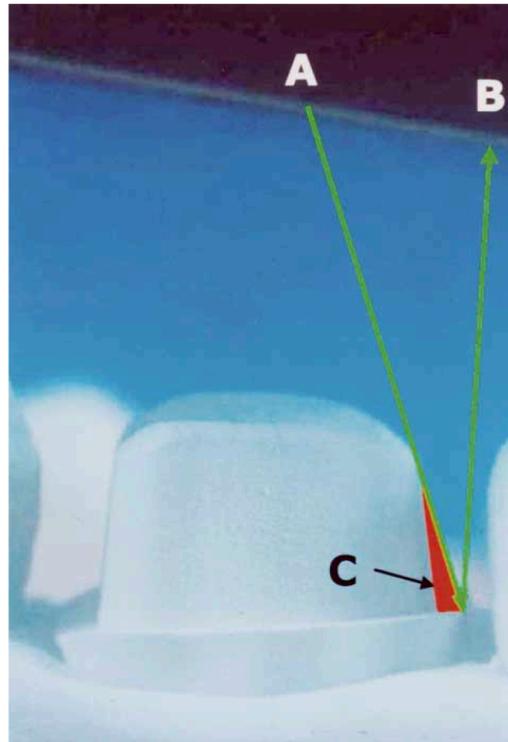
In this technology, data digitization is made with 3D in motion video recordings. The videos are taken with a lens that has a rotating aperture with a structured blue light projection. The motion video is captured by video cameras with high definition. The cameras in the scanner record the object from various angles. Afterwards, the software calculates the 3D coordinates of the object in the space using this data and creating the real object's digital form. A scanning powder must be used lightly in this system to decrease light reflection and more significantly to improve scanning process's connection to the captured images. For example, Lava C.O.S. by 3M uses this technology.<sup>68-70</sup>

### **2.1.8.1.C. The Active Triangulation Technique**

In this technique, the distance of a point from two known points is measured based on it's spatial position according to the angles it makes with the known points, and the known distance between the two points. Geometry and trigonometry commonly uses the triangulation theorem. The light source emanates monochromatic light (CEREC AC Bluecam) or light with various wavelengths (CEREC AC Omnicam). The light is reflected from the object surface and CCD video sensors record the reflection. The space between the video sensor and the light source is already known, thus the objects coordinates in space can be identified according to the angles that both elements produce with the light beams. Scanning powder application is necessary for the CEREC AC Bluecam IOS, and it makes scans without any color. On the other hand, no scanning powder is necessary for CEREC AC Omnicam IOS, and it makes scans with true colors.<sup>69,70</sup>

The biggest disadvantage of systems operating with this technique is the distal shadow phenomenon (Figure 2.7). Distal shadow phenomenon is the shadow that is

created on the object's distance by the beam that the camera reflects on the object. This shadow negatively effects the sharpness of the image and it only seen on the distal surface. If the objects height increases and the conic angle decreases, then the effect of the distal shadow on the image is enhanced <sup>71</sup>



**Figure 2.7** Distal Shadow Phenomenon <sup>71</sup>

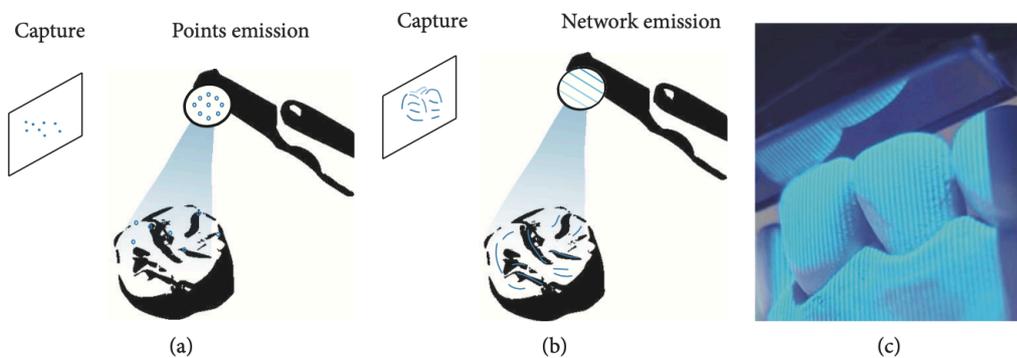
#### **2.1.8.1.D. Parallel Confocal Laser Scanning Microscopy**

The phrase confocal means to have the same focal point. This system is mainly established by the optical systems that are available in the confocal microscopes. Images from different depths can be acquired. The camera emits parallel laser beams. The beams are reflected on the target object surface and then goes back on the same optical path.<sup>70</sup> Light beams that have the same focal point reflect from the surface of the scanned object and return through the filter of the system, and the light beams that have different focal points cannot pass through the system. These returned beams make the 3D image of the scanned object. The whole three-dimensional object is rebuilt by the retrieval of two-dimensional images at different confocal planes. This process is also called “point-and-stitch reconstruction”. This system takes longer when compared with the active wave

front sampling technology. Scanning powder application is not required and the images are captured in color. Dental tissues such as enamel and dentin, or dental materials such as ceramics, composite resins, and amalgam can be imaged with the same sensitivity in this method. Parallel confocal technique was first developed by iTero (Cadent – Align Technology Inc.) TRIOS and iTero are the examples of scanners that use this system.<sup>68,70</sup>

### 2.1.8.2 Image Capture and the Reflection of Light

Active and passive methods can be used to construct 3D images. Only ambient lightning illuminates the object in the passive method, so this method depends on the surface structure of the scanned object. The active light reflection method employs white, blue, or red light from the camera to launch onto the object, thus it's dependency on the surface structure of the objects is lower. The bright spot is emitted onto the object and the space between the object and the light source is measured with triangulation. The light can also be projected in a line or in a net rather than being projected in a dot. The 3D image of the surface can be acquired with the capture of several photos and videos that are taken in a second.<sup>63</sup>



**Figure 2.8** Nature of Light: (a) projection of the points. (b) projection of a mesh. (c) projection of a mesh with an intraoral scanner<sup>63</sup>

### **2.1.9 Indirect Method of Impression for the CAD/CAM Systems**

The impression is acquired from the patient by using the conventional impression method and materials. The obtained impression or the cast model is scanned so that a virtual 3D model is obtained. The restoration that is desired by the operator can be designed on the obtained 3D model. However, the digital data that is obtained from the surface of the conventional impression materials do not provide accurate results.<sup>72,73</sup>

### **2.1.10 Advantages of the Digital Workflow**

1) Critical impression details can be detected in a better manner since the clinician can simultaneously see the scanned surface during the scanning process. Moreover, the operator has the ability to promptly intervene on the missing points while scanning.<sup>67,70,74</sup>

2) The impression can be repeated easily if a large portion of the impression is faulty. The faulted area can be deleted from the existing data and can be scanned again.<sup>67,70,74</sup>

3) It is easy to make addition to the impression. The system has virtual cutting gadget for areas that are not scanned properly. It is also possible to incorporate additional selective scans.<sup>67,70,74</sup>

4) Some CAD/CAM systems allow the operator to select color with the scanner and send this information directly to the dental laboratory.<sup>67,70,74</sup>

5) Tooth preparations' analysis can be made during the session. During the design phase of the software, material thickness, access path, and cement space can be analyzed in an efficient way.<sup>67,70,74</sup>

6) Digital information can be linked to in-office systems, thus restorations can be designed and manufactured by the milling devices in the office without sending any impression to the dental laboratory.<sup>67,70,74</sup>

7) Patients tend to be more comfortable with the digital method when compared with the conventional method.<sup>67,70,75</sup>

8) Working time is significantly less when compared with the conventional impression methods.<sup>67,76</sup>

9) It is possible to connect intraoral scans and computer tomography, digital volume tomography, or extraoral face scan to work with all data.<sup>67,70,74</sup>

10) Easier to follow up patients by seeing the systematically taken intraoral scans over a period of time.<sup>67,70,74</sup>

11) The acquired data can easily be sent to the dental technician by using e-mails or external disks. Moreover, the procedures and the restorative plans can be thoroughly and easily explained to the patient by showing them visually.<sup>67,70,74</sup>

12) There is no waste of conventional impression material in the digital system. Model casting can also be avoided.<sup>67,70,74</sup>

13) In the conventional technique, materials can be distorted in several instances such as when the tray is taken out of mouth. These problems are eliminated in the digital method.<sup>67,70,74</sup>

14) All patient data can be stored digitally for a long time without taking any space in the clinic.<sup>67,74</sup>

15) There is no need for an articulator since the software takes the recorded impressions and bite records and combine these data.<sup>67,70,74</sup>

### **2.1.11 Disadvantages of the Digital Workflow**

1) The clinician has to make an investment to obtain the intraoral scanner. Another cost that the clinician has to pay is the annual fees or special software costs that are integrated to each intraoral scanning system.<sup>76</sup>

2) Learning the use of these scanners and their software to adapt to the everyday clinical practice takes considerable time and attention. Clinicians that are more prone to computers and technology will have less trouble adapting. The best scanning protocol is

still not determined with appropriate studies, so different results can be obtained from using different devices and protocols.<sup>76</sup>

3) Subgingival margins and irregularities are hard to detect by intraoral scanners. These can cause complications in scanning and design steps. The clinician must remove saliva and blood from the scanned area to get good results. The presence of saliva and blood may interfere with the correct production of prosthetic margins.<sup>76</sup>

#### **2.1.12 Intraoral Scanners for Usage in the Direct Method**

1) Trios – 3Shape (Copenhagen, Denmark): 3Shape was developed in Denmark in 2000. The TRIOS system consists of a scanner and a broad design software. Scanning principle is ultra-fast scanning that is the combination of parallel confocal microscopy and structured light. The scanning device has one main button that starts and stops the scan. The device has an inbuilt gyro meter that allows the movement of scans for viewing, and operate the software without touching the screen. The scanner has 2 available types which are plug and play, and the TRIOS Move. Move is the wireless scanner without any plug. It also has an inbuilt fan so that the device does not overheat. The TRIOS camera can be used for the impression of crown restorations, bridge restorations, inlay-onlay restorations, veneers, removable partial dentures, post-core restorations, temporary restorations, and implant supported restorations. After the operator completes the scan, a 3D model is acquired in which the space between the prepared tooth and the antagonist tooth can be measured within the software. The software uses color codes to show whether there is enough space for the restoration. Implant surgical guides, bite splints, night guards, clear aligners and orthodontic bracket guides can also be designed in this software. TRIOS interfaces are all accessible by third-party applications, so it easy to transfer STL, color PLY and DCM files.<sup>77</sup>



**Figure 2.9** 3Shape Wireless and MOVE IOS

2) Cerec Omnicam – Dentsply Sirona (York, PA, USA): In the CAD/CAM systems, the CEREC system has the longest history. Omnicam scanner was introduced to the market in 2012. There are two types of available versions which are tabletop and trolley. The working principle is active triangulation and confocal microscopy. The images are captured by using non-polarized white LED light. This device incorporates video imaging instead of combining static images. Cerec Omnicam is a closed system that is not available to third-party applications. However, the obtained data can be converted to STL format when the system is up to date. Powder application is not necessary.<sup>78</sup>



**Figure 2.10** Cerec Omnicam IOS

3) Emerald S – Planmeca (Helsinki, Finland): The Emeralds S was released to the market in 2019 by the Planmeca company. EmeraldS has a faster scanning protocol when compared with the previous version of Emerald. The working principle of this system is projected pattern triangulation, and the device uses blue, green, and red lasers. EmeraldS has two available scanning tips which are the original scanner tip and the smaller sized Slimline Tip. The scanner tip does not get foggy during the scanning process since it has an inbuilt tip heating system. Scanning powder application is not required. The devices connect to a computer with a USB 3.0 feature. Their systems are open to third party applications, so STL and PLY data output is very easy.<sup>79</sup>



**Figure 2.11** EmeraldS Planmeca IOS

4) Heron IOS – 3disc (Herndon, VA, USA): Heron IOS was released to the industry in the year 2018. Working principle is active stereo imaging made with continuous scans and stitching of color and depth data. Scanning powder application is not required. The device can be connected to computer with the appropriate USB. It also has an inbuilt fan that keeps the scanning tip from fogging. The system is open to third party applications, so STL, PLY or OBJ data output is available.<sup>80</sup>



**Figure 2.12** Heron 3Disc IOS

5) Primescan- Dentsply Sirona (York, PA, USA): It consists of the entire in-house CAD/CAM system that contains a scanner, CAD software, milling machine, and ceramic furnace. The Primecan and the chairside milling machine Primemill was released to the market in 2019. The Primescan is faster when compared with CEREC Omnicam. The company claims that a full arch scan can be done in 45 seconds. The working principles of this system are optical structured light and confocal microscopy with smart pixel sensors. It is claimed to process 1.000.000 3D points per second. Moreover, it claims to accurately scan up to 20mm depth. Scanning powder application is not required. The system can scan real colors and shiny surfaces. Scanning tip does not get foggy due to inbuilt heaters. Crowns, bridges, inlays/onlays, implant restorations, and surgical guides can be designed. The operators can only export STL files since the system is not open to third party applications. The CEREC operating system also has a subscription fee that is paid every year. The unsubscribed users do not get software upgrades.<sup>81</sup>



**Figure 2.13** Primescan Dentsply Sirona IOS

6) iTero Element5D – Align Technology – Cadent (Carlstadt, USA): The device was released in 2019. Align Technology company is the developer of the Invisalign system. As a result, most orthodontists prefer to use the Itero scanner. The working principle of this system is confocal parallel imaging technology that radiates red laser light and white LED light. Scanning powder application is not required. The scanning tip does not get foggy since the scanner has inbuilt heaters. Element5D is the only system that can capture 3D scans, NIRI images, and 2D color images in one scan. It is a scanner that has no design software, and it is open to all third-party applications. However, it can only produce and support STL files.<sup>82</sup>



**Figure 2.14** Element 5D iTero IOS

## **2.1.13 Methods of Digital Impressions**

### **2.1.13.1 Digital Impression of Natural Tooth Supported Prosthesis**

After preparation, the tooth and the surrounding oral tissues must be isolated before taking a digital impression. After the operator is able to achieve retraction and isolation, intraoral scanning is done and digitalization is completed.<sup>83</sup>

### **2.1.13.2 Digital Impression of Implant Supported Prosthesis**

The transfer components that are used in the conventional impression technique are replaced with digital scanning components that are compatible with the implant company so that accurate three-dimensional implant positions can be transferred to the digital system. These scanning components are called implant scanning abutments or scan bodies. Scan bodies have different geometrical designs like emersions and notches. These designs give information about the depth, angle, and hex position of the implant. Different materials can be used to manufacture scan bodies such as polyetherethereketone (PEEK), titanium alloy, aluminum alloy or various resins.<sup>61,84</sup>

During the digital impression of implant supported prosthesis, the first thing to do is to place the scan bodies into their appropriate places in the mouth. Afterwards, the implant, surrounding tissues and the opposite arch is scanned. According to some companies, the impression is taken in a single step directly by the scan bodies. On the other hand, some companies advise that the surrounding tissues around the implant and the depth of implant when the implant neck is visible should be scanned again after the scan bodies are removed. Once the digital impression is taken, the data in STL format is sent to the dental laboratory so that the manufacturing process can be initiated.<sup>61,84</sup>



**Figure 2.15** Scan Bodies of Different Implant Manufacturers <sup>61</sup>

### 2.1.14 Factors that Influence Digital Implant Impressions

There are several studies that evaluate and compare different intraoral scanners regarding accuracy and precision. However, a definite consensus has not been reached, so the scanner that provides the best accuracy is not determined. Even though all intraoral scanners produce a 3D model with enough accuracy to manufacture restorations, they are affected by several factors and have limitations.<sup>85-88</sup>

#### 2.1.14.1 Intraoral Scanner and Software

Several different companies developed intraoral scanners that have different working protocols such as triangulation, confocal microscopy, interferometry, and structured light. Different working protocols produce images with different clarity.<sup>61</sup>

Once the digital impression is acquired, point clouds are gathered from the surface of the scanned object and the software algorithm does surface configuration. The configuration is specific for each intraoral scanner in which point clouds are arranged and meshed into an image. As a result, the three-dimensional image of the scanned object is acquired.<sup>59</sup> For an accurate surface processing of the software algorithm, the point cloud must have high density. Accurate processing produces 3D images that are very similar to

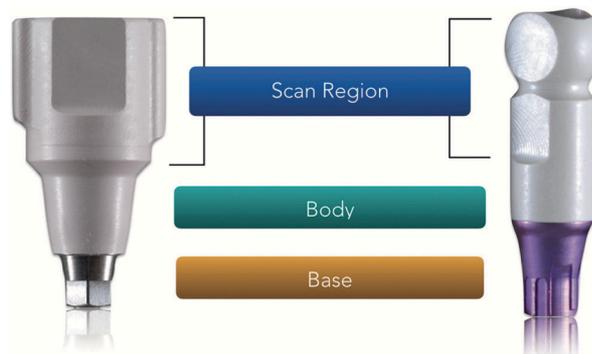
the scanned object. After the scanning process, the software estimates points which are insufficient due to inadequate scanning. These estimations that the software does may be very different from the actual volume of the scanned object, thus leading to distortions.

61

#### 2.1.14.2 Scan Body

Scan bodies are impression components that are manufactured by the implant companies. They allow the exact 3D position of the implants to be correlated with the digital implant library and delivered to the digital system once the scanning is performed with an intraoral scanner. The scan bodies must have appropriate visualization so that a high-precision surface mapping algorithm can work between scan bodies and the digital implant library of the manufacturing company. With the aid of point clouds and algorithm of the CAD program, the implant analog is positioned digitally on a three-dimensional plane (distance, angle, hex position). Scan bodies of different companies have different features regarding the materials it's made of, size, surface configuration, shape, connection types (abutment level, implant level), compatibility, scanner software, and cost.<sup>89</sup>

Scan bodies have three main parts which are apex (scan section), body, and the base. The apex is part where the scan recording is made and allows the transfer of position and angle of implant data. CAD software recognizes the scan section by its flat but asymmetrical surface.<sup>70</sup>



**Figure 2.16** Main Parts of a Digital Scan Body <sup>61</sup>

Point clouds have lower accuracy when the scanned surfaces are deep, angled, sharp, have undercuts or over-configurations.<sup>90,91</sup> The reuse of the scan bodies must also be considered since it can affect accuracy.<sup>92</sup>

Scan body's optimum surface characteristics is highly dependent on the manufacture material. They must be manufactured from metal, titanium alloy, PEEK (polyetheretherketone), aluminum alloy or resins. The compatibility of scan bodies with implants or abutments is affected by the manufacture sensitivities of different materials.<sup>61</sup> Scan bodies have different height ranging from 3 to 17 mm.<sup>93</sup> They must be screwed or clipped to the implant inside the mouth.<sup>14</sup> The scan bodies must fit the implants and analogs perfectly to get accurate results.<sup>94</sup> If excessive force is placed on the scan body while it is being torqued to the implant, the base area may be deformed which can lead to vertical displacement.<sup>95</sup> However, there is not enough evidence regarding this effect on scan bodies made of different materials (titanium and PEEK).<sup>93,95</sup> The manufacturer recommendations must be followed while the scan bodies are torqued to avoid complications.<sup>61</sup>

In multiple implant cases, it is very hard for the scanner to distinguish the scan bodies from each other since they have identical appearances. Thus, it is challenging to obtain images that show the correct position of the implants in the dental arch. Intraoral scanners that have the working principle of combining images, might paste different scan bodies on top of each other if the operator loses the reference points while scanning.<sup>96</sup>

### **2.1.14.3 Scanning Powder Application**

Old generation intraoral scanners required scanning powder application to obtain accurate results. The current generation intraoral scanners do not require it's application. The powder enables the prevention of light reflection in cases where metallic objects are scanned. The patients are usually disturbed by the powder application, and it is hard for the operator to apply the powder in a uniform thickness. If the powder does not have uniform thickness, the scanning cannot be done accurately.<sup>97,98</sup>

#### 2.1.14.4 Protocols of Scanning

Intraoral scanners must be used with specific motions so that an accurate digital model can be obtained. During scanning, the operator has to make sure that the movements are smooth and keeps a constant distance to the object. Scanning must also be tooth centered. According to scanners and their technologies, the scanner must be within 5 to 30 mm of the surface.<sup>99,100</sup>

When the entire arch is planned to be scanned, different protocols have been recommended by companies that produce intraoral scanners that have the working principle of confocal technology. One of the recommendations is linear motion on the palatal-occlusal surface and then following the buccal surfaces. Another recommendation is to make an “S” shaped sweeping motion over the occlusal, vestibular, and lingual surface of each tooth (Figure 2.17).<sup>99</sup> This method terminates image recording at the beginning point and avoids unidirectional errors, so it can minimize spatial distortion. On the other hand, this may be accurate for the linear and undulation motions over the interproximal vestibular surfaces. As a result, operators modified their protocols in areas such as interproximal surfaces, tooth preparation, severely curved central incisors, and canine axis alteration.<sup>70</sup>

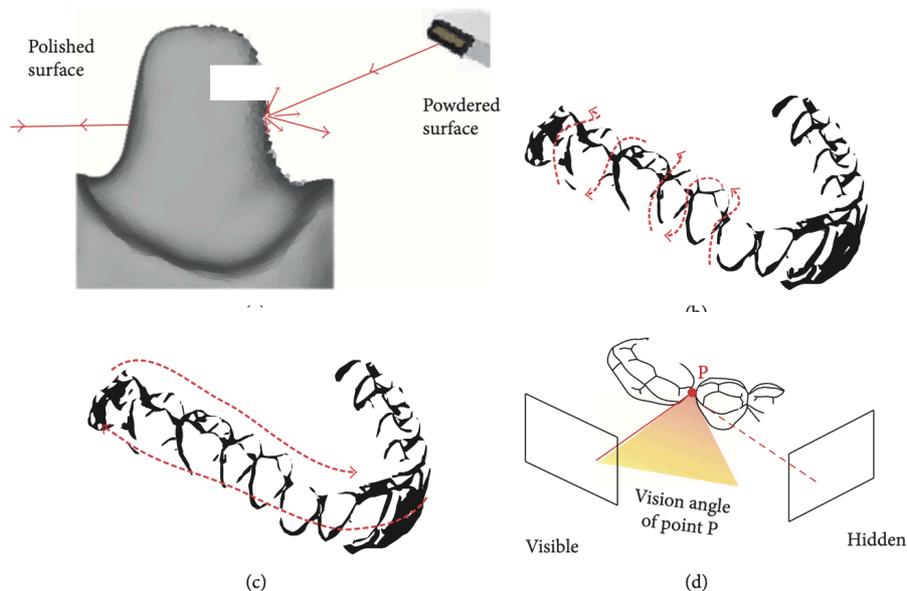
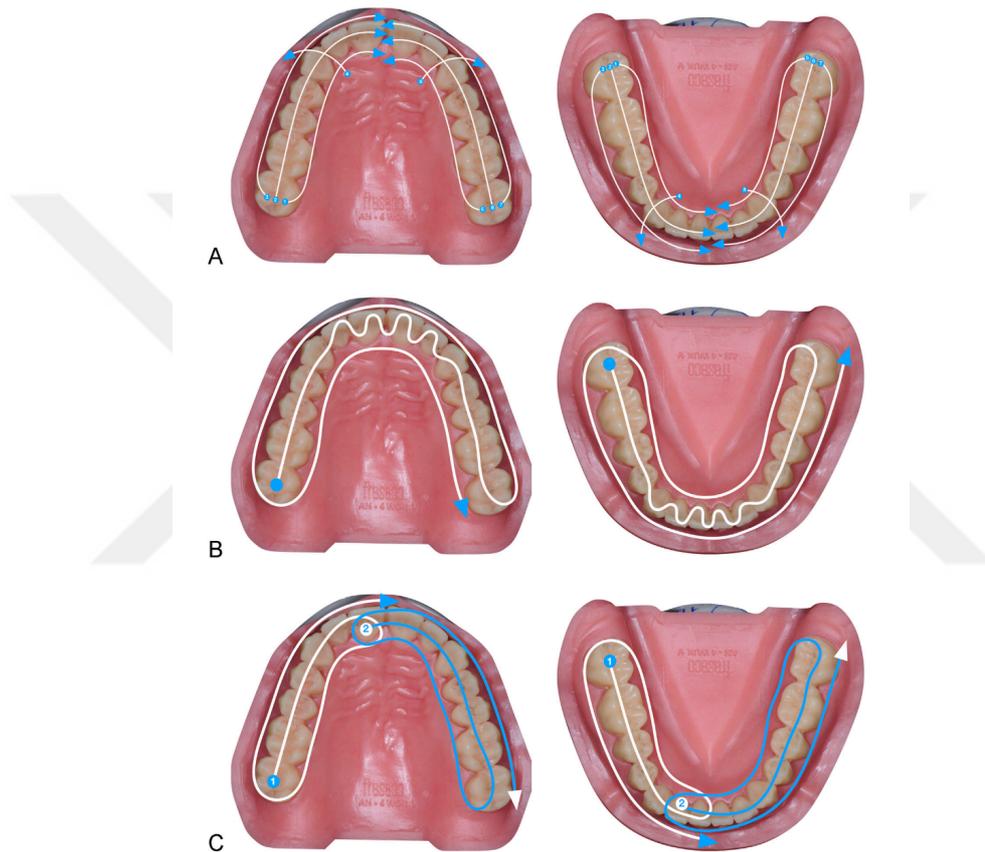


Figure 2.17 Scanning Strategies<sup>63</sup>

Since there are several methods for scanning, companies recommend various protocols for their intraoral scanners. However, a consensus has not been reached regarding which protocol provides the most accurate results.<sup>99,101,102</sup>

More distortion occurs in the anterior region when the scanning starts from the posterior region to preserve mouth opening. The posterior area has a larger surface area, so the scanner can capture more reference points. As a result, the posterior regions are recommended to be scanned first.<sup>103</sup>



**Figure 2.18** Scan Protocols for Different Manufacturers: (a) Cerec Omnicam (b) 3Shape TRIOS (c) Planmeca Emerald<sup>104</sup>

#### 2.1.14.5 Resolution of Image

Scanning system software uses meshing algorithms so that the acquired images can be arranged appropriately. The three-dimensional model is produced once the raw data is edited. On the other hand, in some instances, the algorithm may create different surfaces on the digital image leading to dimensional changes when compared with the original scanned object. To avoid these complications, the scanners must be regularly

calibrated according to the manufacturer recommendations. Moreover, the scans must be performed in high resolution mode so that better data can be acquired.<sup>61,90</sup> High resolution scans provide better data, but they come with several disadvantages such as scans taking longer time and data with large size that take a lot of system memory.<sup>105</sup>

#### **2.1.14.6 Scanned Arch Length and Area**

Satisfactory reference points between point clouds are hard to acquire when the scanned arch length increases. Image combination will not be possible when the images are acquired separately in such cases. This may lead to complications such as distortion and optical noise in the image, or some surface regions may be cut out by the software. It was reported that the increase of scanning time results in the decrease of impression accuracy.<sup>85,86,106</sup> The complications may be caused by the error in the process of digital point meshing. When the scanning interval takes longer, more point meshing errors are anticipated thus the scan becomes susceptible to errors.<sup>106</sup>

The scanned arch is broken down to quadrants in accordance with the distance from the first obtained image. The first scanned arch is the first quadrant. The second quadrant is the area which is at a greater distance from where the first image was acquired. In a study by Gimenez *et al.*<sup>107</sup>, it was stated that the images had more distortions in the second quadrant.

Posterior teeth have larger surface areas, thus they provide more reference points in the acquisition of the first image by the intraoral scanner. As a result, posterior region is usually preferred as the first scanning area. In this instance, since the scanning moves from the posterior region to the anterior region, more distortion is observed on the anterior region. Anterior region has less surface area thus it can yield less data leading to dimensional changes in the image.<sup>108</sup>

Interproximal and gingival areas are hard to scan since the intraoral scanning tip cannot reach these areas in the correct angle. Subsequently, less data is acquired in these areas, so more distortion occurs in the image.<sup>109</sup>

#### **2.1.14.7 Artifacts**

Artifacts are artificial appearances that are made by humans in radiologic, ultrasonic, or microscopic examinations. They occur due to shadows created by undercuts areas or neighboring structures. Saliva or blood may cause moisture that can decrease the quality of data since optical reflections may also lead to the occurrence of artifacts.<sup>110</sup>

#### **2.1.14.8 Optic Noise**

If light is reflected to the intraoral scanner during the scanning process, impacted images are captured, and optic noise arises. To decrease optical noise, scanning should be done in high resolution so that dimensional changes that happen in the surface configuration process is averted. Optic noise can be identified on the obtained images, so the operator can repeat the scanning process.<sup>111</sup>

#### **2.1.14.9 Experience of the Operator**

To use the operating systems efficiently, and integrate it to everyday clinical practice, the operator has to spend a considerable amount of effort and time. The operator must learn the system extensively to integrate the intraoral scanning systems to dental practices. In the acquisition of an accurate digital impression, it is essential that the operator is familiar with the equipment and has enough knowledge. Most clinicians who are prone to using computer, and who are interested in technology usually find it easier to use these systems. By using different equipment and scanning methods, different results can be obtained.<sup>90</sup>

It was reported that clinicians who are younger and who were raised with the digital technology adapt faster to the digital workflow. Older clinicians who have a habitual workflow in the clinic find it harder to adapt to the digital workflow.<sup>112</sup>

#### **2.1.14.10 Implant Position**

In theory, digital impressions should not be affected by the implant position since the material deformation due to implant angulation, or movement of the impression coping does not occur. However, there are different results obtained by different studies regarding this matter. For example, study by Gimenez *et al.* reported that implant

angulations do not affect the accuracy of digital impressions.<sup>90</sup> On the other hand, Gomez-Polo *et al.*<sup>113</sup> reported that implant angulation affects the scanning accuracy.

Since the length of visible scan body decreases when the gingival depth of the implant increases, impression accuracy can be affected. It was reported that if the scan bodies are buried in the gingiva for more than 1mm, the impression accuracy is affected negatively.<sup>114</sup>

#### **2.1.14.11 Patient Related Factors**

Digital impressions can be affected by the saliva, mouth opening restrictions, and patient movements during the scanning process. When the jaw moves, the mucosa shape may change, thus the intraoral scanner might have trouble location reference points while scanning.<sup>115</sup>

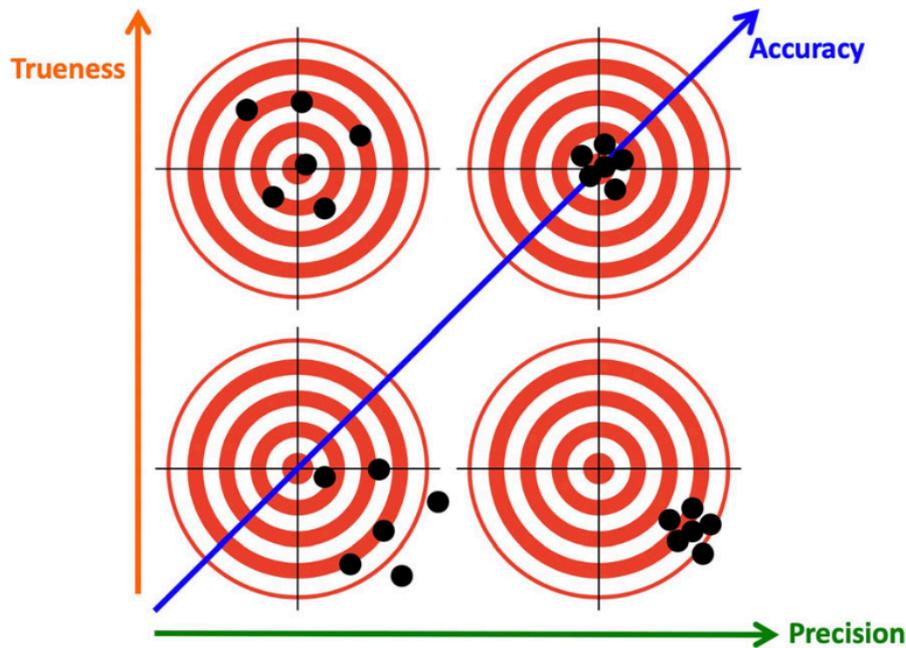
Intraoral scanner's image capture ability and mesh quality values are highly affected by ambient illumination. To have better outcomes with digital impressions, different lightning conditions are recommended based on the scanner and planned procedure.<sup>116</sup>

### **2.2 Methods for the Evaluation of Implant Impression Accuracy**

Precision and trueness define the concept of impression accuracy. Trueness is “the digitizer’s ability to make a copy of a dental arch as close to its natural shape as possible without deformation”. Precision is “the difference between images made by repeated scanning under the same conditions. Intraoral scanners must provide coherent outcomes across similar scans that are made at different times, and they must provide accurate results.<sup>117</sup>

The scanned object’s real geometry in space must be determined to calculate the accuracy of the impression.<sup>118</sup> Microscopy, computed tomography, and three-dimensional photogrammetry were examples of methods used to examine accuracy. However, these methods were not able to provide enough data for a conclusion to be reached.<sup>119,120</sup> Recently, appropriate superimposing programs are used to create 3D copies of models that are made with impressions and then compare them by using a highly

accurate reference dataset (the master model) through 3D deviation analyses and linear measurements.<sup>117</sup>



**Figure 2.19** Relationship Between Trueness and Precision as Defined by ISO (1994)<sup>118</sup>

### 2.2.1 Reference Scanners

The models must be scanned by using industrial optical scanners which can scan with high accuracy so that implant impressions and the actual implant positions can be compared. Another way is to determine the coordinates of the implant by using coordinate measuring devices.<sup>121,122</sup>

Dimensional discrepancies can still occur when the master models are scanned with industrial optical scanners. However, these discrepancies are very small and vary between 6 and 10 $\mu\text{m}$ <sup>123</sup>. These deviations are higher when compared with a coordinate measuring device, but since they are clinically low their measurements are accepted for comparisons in studies.<sup>85,124</sup>

Coordinate measuring devices have the accuracy of 1  $\mu\text{m}$ , but they also have several disadvantages. For example, scanning speed is very low and interproximal regions

are scanned in a complex manner due to geometric configurations.<sup>121,122</sup> There are a few devices that can beat these disadvantages such as the Zeiss LineScan 2-25 which is connected to a coordinate measuring device. Zeiss LineScan 2-25 is machine that is locked to a probe holder on a coordinate measuring device (Contura G2). The laser line scanner in this setup does controlled movements over the artefact that is placed on the coordinate measuring device. The artefacts front and sides are covered with three scans which are in YZ direction with 90°, 75°, 105° angles. The artefacts top and bottom is covered with two scans which are in ZX direction with 15°, -15° angles. Laser triangulations records the data with the use of point clouds.<sup>125</sup>

Unfortunately, these scanners' size and using technique keep them from being used inside the mouth. As a result, they can be used in in vitro studies that assess impression accuracy and in vivo studies that assess fit of the prosthetic parts that are manufactured after impression taking.<sup>126</sup>

### **2.2.2 Digital Data Evaluation**

The accuracy of scanning systems is evaluated by using quality control softwares. Quality control software in engineering and industry is used to develop the “reverse engineering” concept. By reverse engineering, any object that is designed in a computer environment is scanned by using high-resolution scanners. Afterwards, the acquired images of the model designed in the computer and the produced model are compared with each other. Specialized software is available with most of the industrial scanning devices. The scanned images of objects can be constructed in a virtual environment with the help of these software. If multiple images are acquired, then the software combines these images to produce a single image of high-quality. The coordinates of points in the image are matched in space as the quality control software merges and benchmarks them. Each spatial point has x, y, and z coordinates. Correspondent with the efficiency of the scanner, each image has between 800,000 and 4,000,000 dots. Each point is merged with the points that have the same coordinates with using the comparison and merging processes of the software. The integration of the images is done with this method. The data export can be done in STL form after the end of the control process.<sup>123,127,128</sup>

The assessment is performed by comparing the distance and angle data between the master model that is acquired with the reference scanner and the three-dimensional

model that is acquired with the digital impression. The three-dimensional comparison is made with the evaluation of post-measurement displacement of reference points on x,y, and z planes. On each plane, differences are determined and acknowledged with three-dimensional vector calculation.<sup>123,129</sup>

The distance and angle parameters of the reference model and obtained model are compared in the three-dimensional vector calculations. Superimposition is one technique of comparison in which the reference model and the obtained model is superimposed on top of each other. The STL files are exported to the reverse engineering software. The software uses best-fit algorithm to assess accuracy by comparing dimensional differences. The images are overlapped so that the dimensional differences are revealed to understand the level of precision.<sup>76,123,129</sup>

Some studies revealed that superimposing may lead to deviations. Therefore, other researchers determined reference points and lines on the scan bodies and compared them to assess the differences between angles and distance of implants on the reference and obtained models.<sup>10,76,90</sup>

To sum up, there are several reference scanners and comparison methods available to assess the accuracy of impressions. As a result of different impression techniques, impression accuracy varies thus implant prosthesis manufacture and fit of the implant-prosthesis interface is affected.

### **2.2.3 Passive Fit and Outcomes of Non-Passive Fit**

When the infrastructure of the prosthesis does not cause tension or force on the implant, bone surrounding the implant and the abutment, passive fit is achieved. The implant's impression directly affects the manufactured prosthesis' precision and the fit of the prosthesis. In conclusion, a precise impression is required to produce a passive-fitting prosthesis. For an implant treatment to be successful in the long-term, the passive fit between the prosthetic infrastructure and the implant abutment is essential. Abutment-implant-bone complex's overload can be prevented if the substructure and the abutment is in passive and correct position.<sup>130,131</sup>

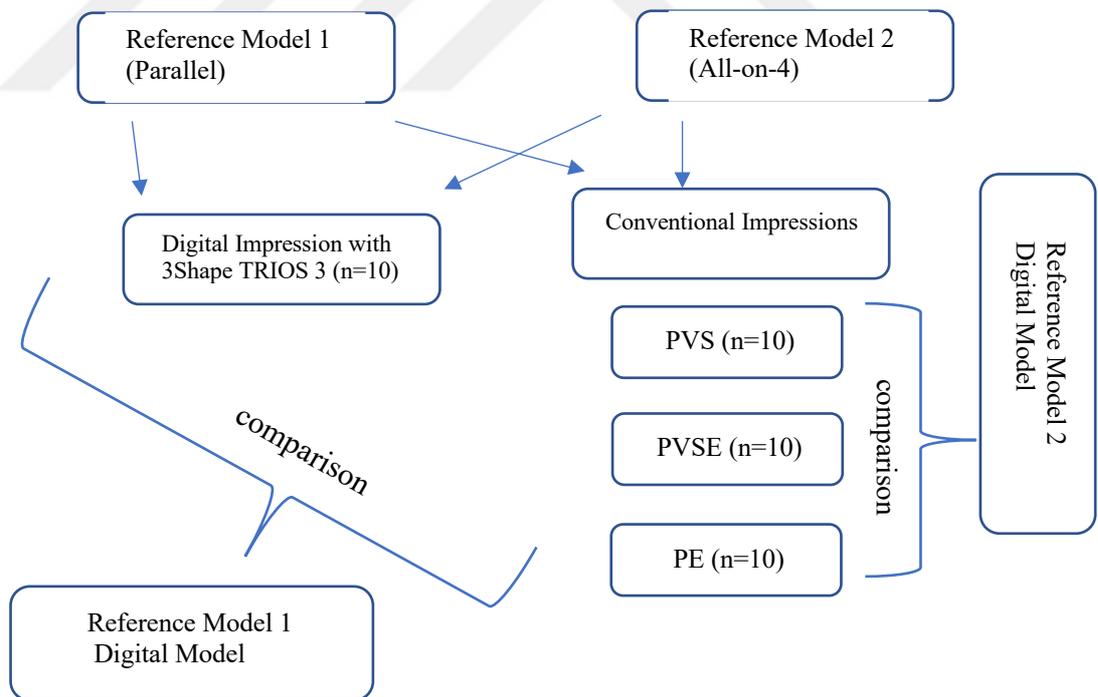
Teeth have the ability to move 25-100 microns in the axial direction and 56-108 microns in the lateral direction. Periodontal ligaments directly affect this movement. Therefore, natural teeth tend to migrate if they are overloaded with forces. On the other hand, implants have the ability to move 3-5 microns in the axial direction and 10-50 microns in the lateral direction, thus implants transfer forces directly to the bone surrounding them, principally on the alveolar crest.<sup>132-134</sup>

Since the implants do not have any periodontal ligament, excessive force transmission to the bone is ten times more when compared with natural teeth. As a result, if the prosthetic substructure is in imbalance, the implant's ability of compensation is very low. If the prosthesis-abutment interface is incompatible then several complications can occur such as pain, gingival inflammation, marginal bone loss, abutment screw loosening or fracture, and prosthesis or implant fracture. If there is incompatibility on a horizontal plane, then tensile and bending stresses increase between the screw of the abutment and the prosthesis. If there is incompatibility on a vertical plan, then the overload on contacting surfaces that can lead to the loosening or breakage of the screw.<sup>135</sup>

The human biology can adapt, but how much misfit it can tolerate is unclear.<sup>136</sup> The perfect passive fit is almost impossible obtain and the degree of acceptable misfit is still uncertain.<sup>137</sup>

### 3. MATERIALS AND METHODS

The aim of this study is to evaluate and compare the accuracy of digital and conventional impression techniques in multiple implants with different angulations. In this study, two complete edentulous polyurethane upper jaw models were used. 4 parallel implants were placed in the first reference model and 4 implants according to All-on-4 protocols were placed in the second reference model. Digital and conventional impressions, using polyvinylsiloxane, polyether, polyvinyl siloxane ether, were taken 10 times from each reference model. Models were splinted before any conventional impression was taken. The obtained cast models were scanned using a digital laboratory scanner (3Shape E1 Lab Scanner, Copenhagen, Denmark) to obtain STL data of the models. The reference models were also recorded using the same device. Afterwards, all of the acquired digital data was registered to a virtual environment with a reverse engineering program (Geomagic Control X, Geomagic, USA). The findings were evaluated statistically.



**Figure 3.1** The Workflow of the Study

The same operator performed the six stages of this study:

- 1) Fabrication of the reference models
- 2) Acquisition of the 3D reference models
- 3) Taking digital implant impressions with an intraoral scanner
- 4) Taking conventional impressions with polyvinylsiloxane, polyether, and polyvinyl siloxane ether
- 5) Pouring of the casts of conventional impressions
- 6) Digitalization of the models cast from conventional impression
- 7) Evaluation with Geomagic Control X
- 8) Statistical analysis of the findings

**Table 3.1** Test Materials Used in the Study

<b>Material</b>	<b>Lot Number</b>	<b>Manufacturer</b>
Implants	050222-0202	Mode Medikal, Istanbul, Turkey
Implant multi-unit abutments	22312230	Mode Medikal, Istanbul, Turkey
Implant impression copings for direct technique	2317183	Mode Medikal, Istanbul, Turkey
Implant analogs	Experimental	Mode Medikal, Istanbul, Turkey
Implant multi-unit scan bodies	Experimental	Mode Medikal, Istanbul, Turkey
Additional silicon impression material heavy body	383303	Zhermack Hydroise, Zhermack S.p.A, Italy
Additional silicon impression material light body	418827	Zhermack Hydroise, Zhermack S.p.A, Italy
Polyvinylsiloxane adhesive material	276647	DMG Tray Adhesive, DMG Chemisch-Pharmazeutische Fabrik GmbH, Hamburg, Germany
Polyether impression material	9190883	3M Impregum Penta Soft, 3M Deutschland GmbH, Germany

Polyether adhesive material	9920418	3M Polyether Adhesive, 3M Deutschland GmbH, Germany
Polyvinyl siloxane ether impression material	231891005	Identium, Kettenbach GmbH, Germany
Polyvinyl siloxane ether adhesive material	230011	Universal Adhesive, Kettenbach GmbH, Germany
Pattern acrylic resin	2210052	Pattern Resin LS, GC Europe NV, Belgium
Dental stone type IV	21-00237	Angel Dental Stone, Turkey
Anti-glare spray	8692103003822	BT-37, Beta Proses Özel Kimyasallar San ve Tic. Ltd, Tekirdağ, Turkey

**Table 3.2** Devices Used in the Study

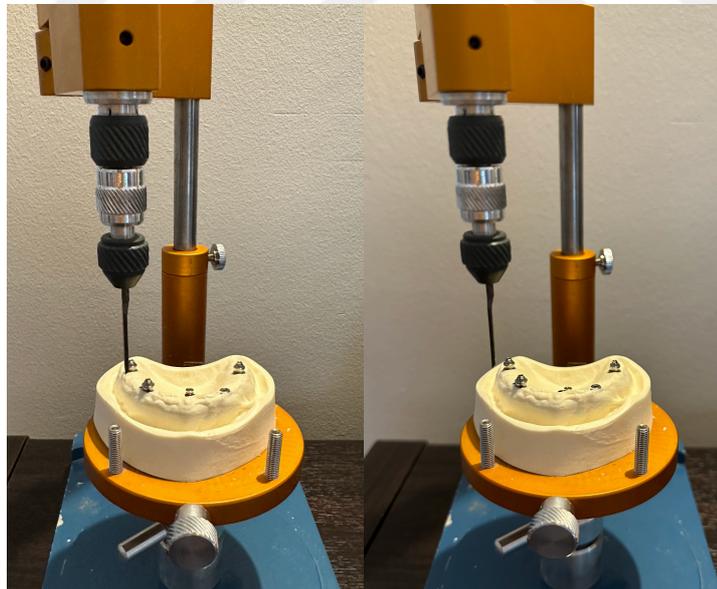
<b>Device</b>	<b>Place of Production</b>
Parallelometer	Rotaks Dent, Istanbul, Turkey
Implant system ratchet	Ratchet with torque, Mode Medikal, Turkey
Auto-mixing machine	Pentamix 2, 3M ESPE, Germany
Garant dispenser	Garant Dispenser, 3M ESPE, Germany
Stone vacuum mixer	Smartmix, Amann-Girrbach GmbH, Pforzheim, Germany
Intraoral scanning machine	3Shape TRIOS 3, Copenhagen, Denmark
Extraoral scanning machine	3Shape 1E Lab Scanner, Copenhagen, Denmark
Computer – Geomagic Control X	Geomagic, USA

### **3.1 Reference Model Fabrication**

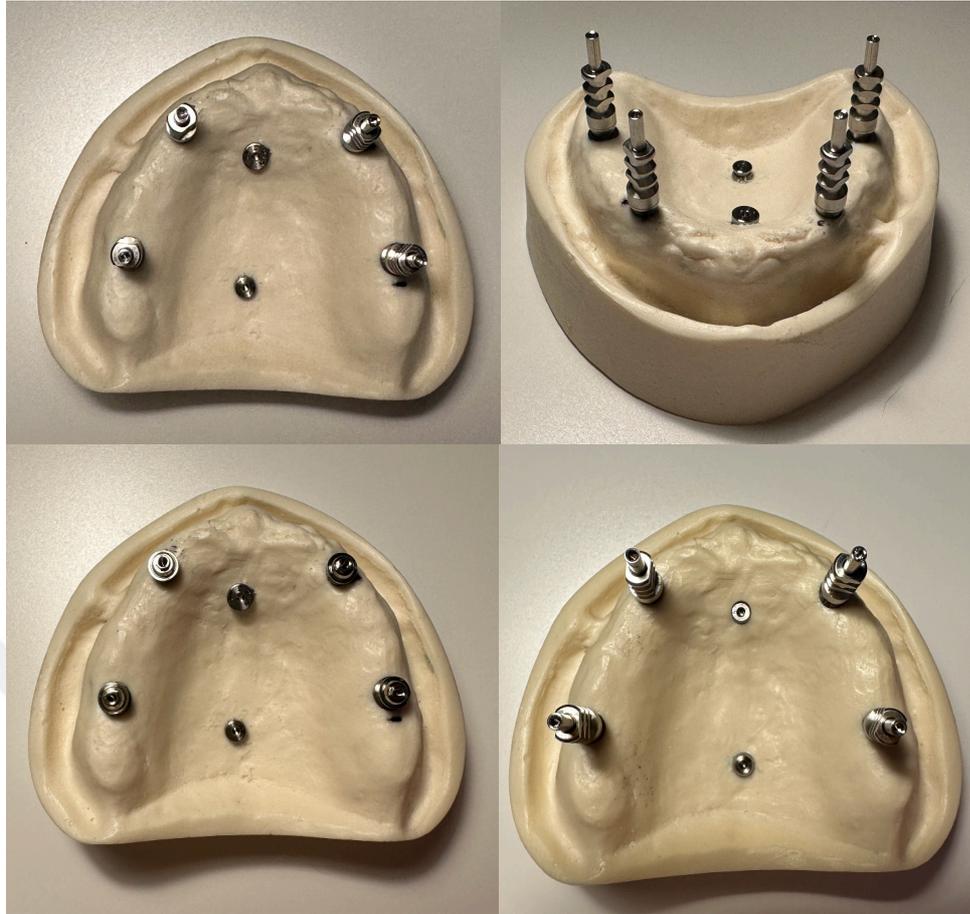
Two standard edentulous maxilla models made of polyurethane were used in this study (Edudent, Istanbul, Turkey). Polyurethane models were preferred since polyurethane is quite similar to the natural bone tissue, thus implementation of the implants is easy, and implants are provided with good stability. Group 1's reference

model had four parallel implants (Mode Medikal, Istanbul, Turkey) which were placed in the canine and first molar region. All implants were perpendicular to the occlusal plane thus the angle of the implants were considered as 0°. Group 2's reference model had four implants which were placed in the canine and first molar regions. The anterior implants were parallel to each other and was perpendicular to the occlusal plane, so the angle of these two implants were considered 0°. The posterior implants were placed distally with 30° to the perpendicular axis on the occlusal plane to simulate the clinical conditions of all on four technique. Parallelometer was used to determine the correct angles of implants while they were placed on the models. Implants were placed according to the manufacturer's protocols.

Two implants were placed in the midline of the palate of both models to serve as reference pieces. One of the references was placed near the incisive foramina and the other was placed posterior to the last implants which were in the molar region. In order to standardize the impression taking process, stock open trays with window space corresponding to the implant site were used in each impression.



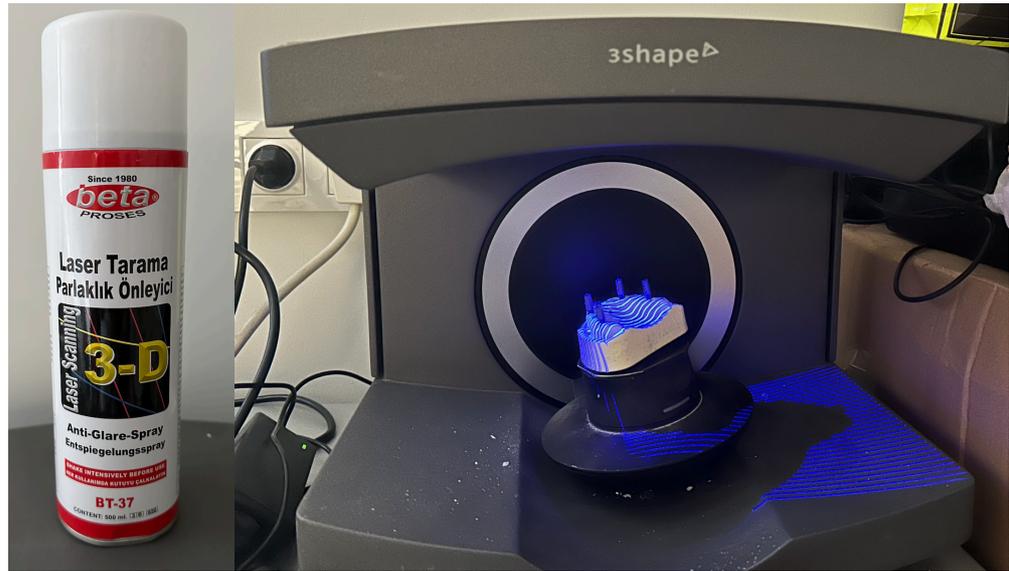
**Figure 3.2** Reference Models on the Parallelometer



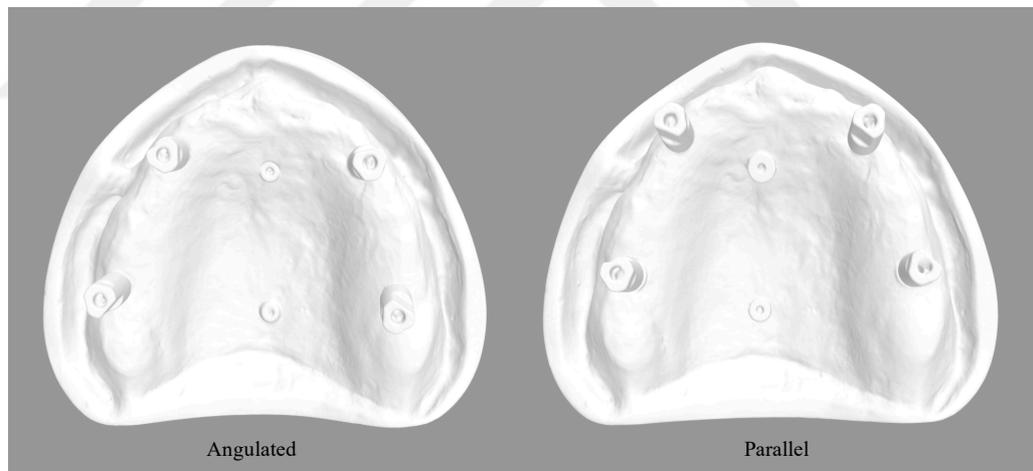
**Figure 3.3** Finalized Versions of the Reference Models

### **3.2 Acquisition of the 3D Reference Models**

After the placement of implants, 4 straight multi-unit abutments were placed on the Group 1's model with 25 Ncm torque according to the manufacturer's instructions. Afterwards, multi-unit scan bodies were placed with light finger force (5-10Ncm) according to the manufacturer's instructions. 2 straight multiunit abutments were placed on the anterior implants and 2 angled multiunit abutments were placed in the posterior implants of Group 2's reference model with 25 Ncm torque according to the manufacturer's instructions. The positions and angulations of the abutments were checked with the use of the parallelometer. The obtained reference models were sprayed with an anti-glare spray (Beta Proses BT-37, Tekirdağ, Turkey) to obtain accurate scans by eliminating reflections that can cause discrepancies. Both models were scanned using the 3Shape 1E Lab Scanner, and the STL files of the reference models were obtained.



**Figure 3.4** Anti-Glare Spray and Scanning with 3Shape 1E Lab Scanner of the Reference Models

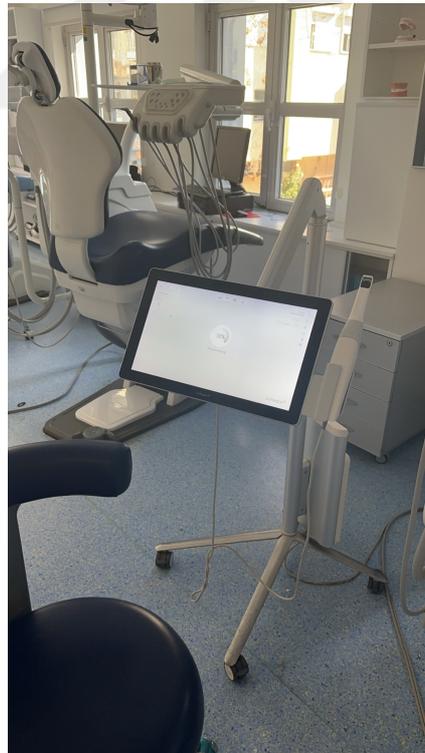


**Figure 3.5** Scanned Virtual Reference Models

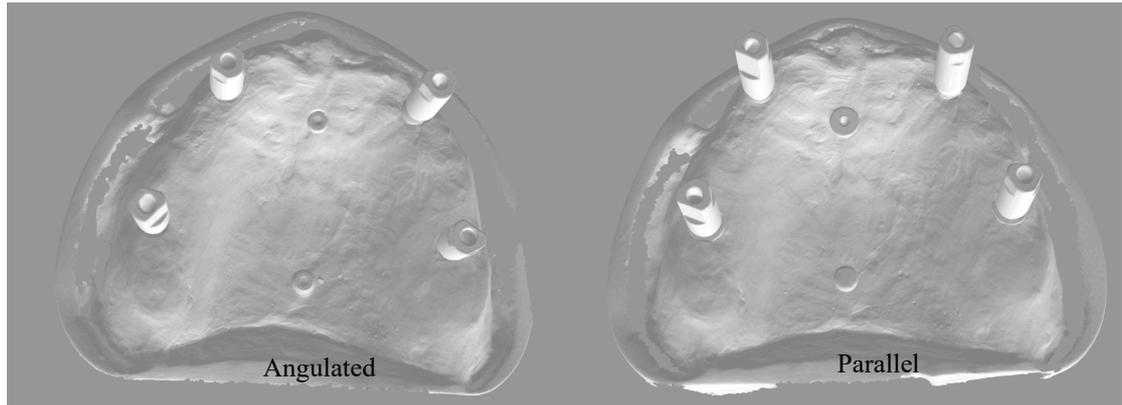
### **3.3 Taking Digital Impressions with an Intraoral Scanner**

A single operator performed all of the scanning process. Each reference model was scanned 10 times according to the power analysis that was performed at the beginning of planning phase of the current study. 3Shape Trios 3 intraoral scanner with an external computer connection which had the interface program of the manufacturer was used.

After logging in to the main screen, new patient option was selected, and a record for each scan was created. For each scan, the new case option of the software was selected in which implant-supported prosthesis treatment option was picked. It is important to select the type of restoration prior to scanning so that the software can figure out which restoration is planned and use the correct algorithm and level of sensitivity. Maxilla was selected as the jaw to be scanned and before the beginning of each scan “scanner ready” message was seen. All of the scans were performed according to the Trios User Instructions. Firstly the occlusal surfaces of the models were scanned starting from the posterior region. Afterwards, the scanner tip was inverted, and turned to the vestibular surface at 45° angle. Vestibular surfaces were scanned by maintaining this angle. Consequently, the scanner tip was turned over to the palatal surface at 45° angle. All palatal surfaces were scanned. The scanned surfaces were thoroughly examined at the end of each scan and the present artifacts were cut. The missing regions were scanned again therefore completing the digital impression. The acquired scans were saved as STL files using the export option of the software. The obtained data was taken from the computer using a USB device.



**Figure 3.6** Trios 3 Device in Yeditepe University Faculty of Dentistry



**Figure 3.7** Scanned Reference Models with Trios 3 Device

### **3.4 Taking Conventional Impressions with Polyvinylsiloxane, Polyether, and Polyvinyl Siloxane Ether**

The scan bodies on both reference models were removed, so that conventional impressions can be taken. On each reference model, 4 multi-unit impression copings were placed and screwed with light finger force (5-10 Ncm) according to the manufacturer's instructions. With all materials, direct splinted technique was used to take impressions and 10 impressions were taken for each material making a total of 30 impressions per each reference group. A prefabricated resin bar was used to splint the impression copings. The bar was cut with a diamond burr according to the distance between the copings. The cut bars were attached between the copings by using cold acrylic resin (Pattern Resin LS, GC, Belgium). Cold acrylic resin was prepared in an incremental manner. Manufacturer's fine brush was dipped into the liquid component of acrylic resin, so that the brush is wet on the top. Afterwards, the wet brush was dipped to the powder component of the acrylic resin delicately and the powder on top of the brush starts to polymerize within seconds. The resin on the brush was then applied on the prefabricated bar so that it joins with the impression coping. The resin was laid to set in room temperature for 3 minutes according to the manufacturer's instructions. These steps were repeated for each material's impression process. Stock open trays with window space corresponding to the implant site were used in each impression.



**Figure 3.8** Splinting of the Impression Copings with Pattern Resin

### 3.4.1 Conventional Impression with Polyvinylsiloxane

Fast set Hydroise heavy body and Hydroise light body (Zhermack S.p.A, Italy) polyvinylsiloxane was used as the impression material. DMG tray adhesive for A-silicones (DMG, GmbH, Germany) was applied to each impression tray before each impression and waited for 3 minutes according to the manufacturer instructions. Auto mixing machine (3M ESPE Pentamix 2) was used to avoid mixture inconsistencies and air bubbles in the putty mixture. Garant dispenser gun was used to mix the light body. The mixed heavy body was placed onto the tray and then the light body was poured onto the putty with the help of the dispenser gun to obtain a one-step impression. All impressions were taken in a temperature controlled environment (25°C with a relative humidity of 50%). Throughout the setting time of the material, bilateral finger pressure was applied so that the seating load of each impression is standardized. The complete set of the impression material was waited for 4 minutes according to the manufacturer's instructions. Once the material was set, impression copings were carefully unscrewed, and the tray was removed from the model in antero-superior direction. The analogs of implants were attached to the copings screwed together in accordance with the instructions of the manufacturer.



**Figure 3.9** Application of PVS Tray Adhesive and PVS Impression Material



**Figure 3.10** Pentamix and Garant Dispenser



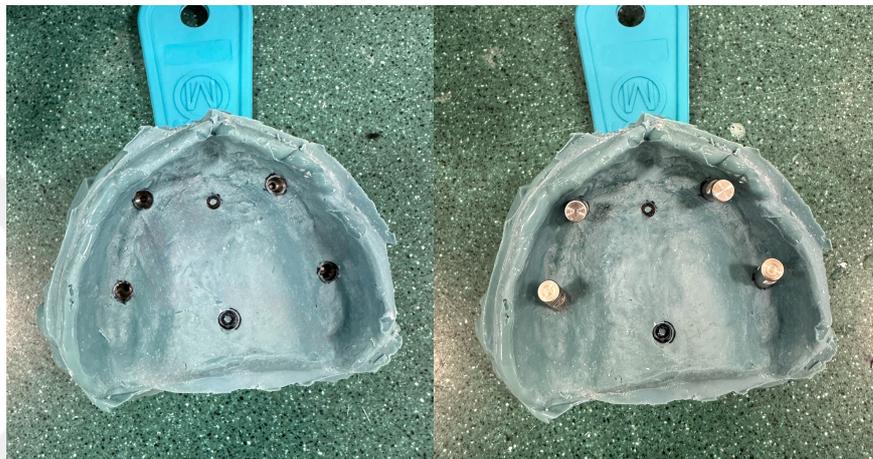
**Figure 3.11** Impression with PVS

#### **3.4.2 Conventional Impression with Polyether**

Soft Monophase polyether (3M Impregum Penta Soft, GmbH, Germany) was used as the impression material. 3M polyether adhesive (3M, GmbH, Germany) was applied to each impression tray before each impression and waited for 15 minutes according to the manufacturer instructions. Auto mixing machine (3M ESPE Pentamix 2) was used to avoid mixture inconsistencies and air bubbles in the mixture. The impression material was poured onto the tray from the auto mixing machine. All impressions were taken in a temperature controlled environment (25°C with a relative humidity of 50%). Throughout the setting time of the material, bilateral finger pressure was applied so that the seating load of each impression is standardized. The complete set of the impression material was waited for 3 minutes and 15 seconds according to the manufacturer's instructions. Once the material was set, impression copings were carefully unscrewed, and the tray was removed from the model in antero-superior direction. The analogs of implants were attached to the copings screwed together in accordance with the instructions of the manufacturer.



**Figure 3.12** Application of PE Tray Adhesive and PE Impression Material



**Figure 3.13** Impression with PE

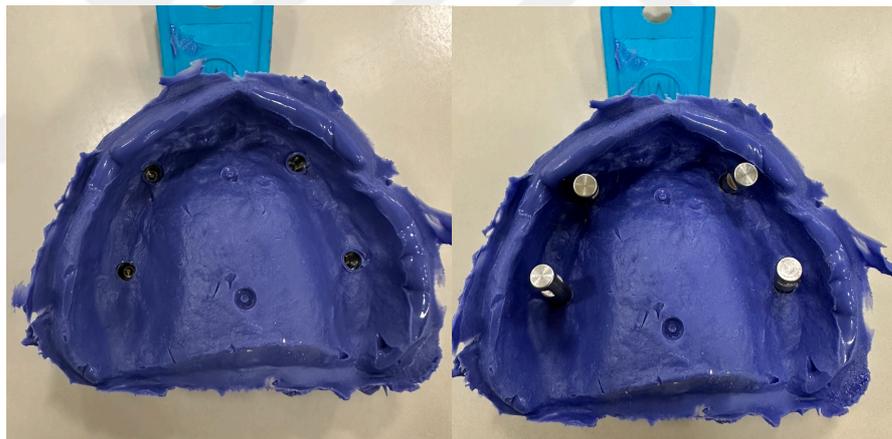
### 3.4.3 Conventional Impression with Polyvinyl Siloxane Ether

Identium medium bodied polyvinyl siloxane ether (Kettenbach, GmbH, Germany) was used as the impression material. Identium adhesive was applied to each impression and waited for 5 minutes according to the manufacturer instructions. Auto mixing machine (3M ESPE Pentamix 2) was used to avoid mixture inconsistencies and air bubbles in the mixture. The impression material was poured onto the tray from the auto mixing machine. All impressions were taken in a temperature controlled environment (25°C with a relative humidity of 50%). Throughout the setting time of the material, bilateral finger pressure was applied so that the seating load of each impression is standardized. The complete set of the impression material was waited for 4 minutes and 30 seconds according to the manufacturer's instructions. Once the material was set, impression copings were carefully unscrewed, and the tray was removed from the model

in antero-superior direction. The analogs of implants were attached to the copings screwed together in accordance with the instructions of the manufacturer.



**Figure 3.14** Application of PVSE Tray Adhesive and PVSE Impression Material



**Figure 3.15** Impression with PVSE

### 3.5 Pouring of the Casts of Conventional Impressions

Before cast was poured, impressions were checked to ensure that there is no discrepancy, air bubbles, loose impression coping, uncorrected sets, or other errors. Prior to pouring, each impression was boxed to provide a 3 cm base. Double mixing method was used to lessen the effect of the dimensional change of the stone. Dental stone type IV (Angel Dent, Turkey) was poured into the impression. 20 ml of distilled water was added to 100g of stone powder according to the manufacturer's recommendations and the stone was vacuum mixed (Smartmix, Amann-Girrbach, Germany). As per the advice of the manufacturer, 120 minutes of setting time was allowed before the impressions were detached from the casts. Screws were carefully loosened to detach the impressions from the casts. The edges of the casts were trimmed and labeled as preparation for the digitalization of the conventional models. The same operator performed all of the pouring of the casts. Prior to scanning, all models were kept at room temperature for 24 hours.



**Figure 3.16** Example of a Conventional Impression Cast

### 3.6 Digitalization of the Models Cast from the Conventional Impression Techniques

In order to make comparative measurements, appropriate multi-unit abutments and scan bodies were placed on the dental stone models so that the digital scanning can be performed by using a laboratory scanner. The positions and angles of the abutments were checked by using the parallelometer. Each model was sprayed with an anti-glare

spray (Beta Proses BT-37 Spray) to obtain accurate scans by eliminating reflections that can cause discrepancies. Models were fixed onto the digital laboratory scanner in a correct position (3Shape 1E Lab Scanner, Copenhagen, Denmark). After logging in to the main screen, new patient option was selected, and a record for each scan was created. Maxilla was selected as the jaw to be scanned and before the beginning of each scan “scanner ready” message was seen. All of the scans were performed according to the 3Shape User Instructions. The scanned surfaces were thoroughly examined at the end of each scan for any errors. The acquired scans were saved as STL files using the export option of the software. The obtained data was taken from the computer using a USB device.



**Figure 3.17** Scanning of the Conventional Impression Models with 3Shape 1E Lab Scanner

### **3.7 Evaluation with Geomagic Control X**

The digital data that was obtained from the intraoral scanner and laboratory scanner was opened in Geomagic Control X (Geomagic, USA) software. No file conversion was performed because all of the acquired data was in STL format.

Reference models and dental stone models were matched in this software with the aid of reference points. The data of the reference models was aligned one by one with the intraorally scanned models and conventional models. The software aligned the model by firstly using the initial alignment option and then the best-fit alignment option. The best

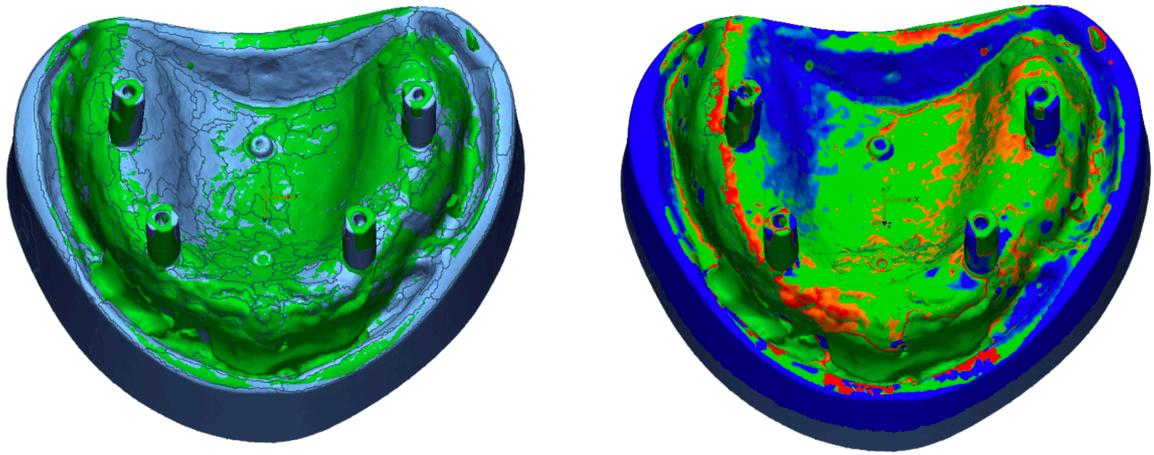
fit was registered according to the reference points and implant positions. Once the registration was completed, the 3D Deviation color map feature of the Geomagic Control X software was used. In this feature, the software generated color maps correlating with the degree of 3D deviation produced for each model. The software performed three-dimensional deviation measurements of implant center points and impressions surfaces.

The software provides the root mean square (RMS) value of the square root of the mean deviations in the determination of the amount of 3D deviation. The amount of deviation in x,y,z places are calculated in 3D and the converted to a mathematical value. The unit parameter on the software was chosen as mm. The color map of all of the samples were created, and the amount of deviation at the selected points were reported.

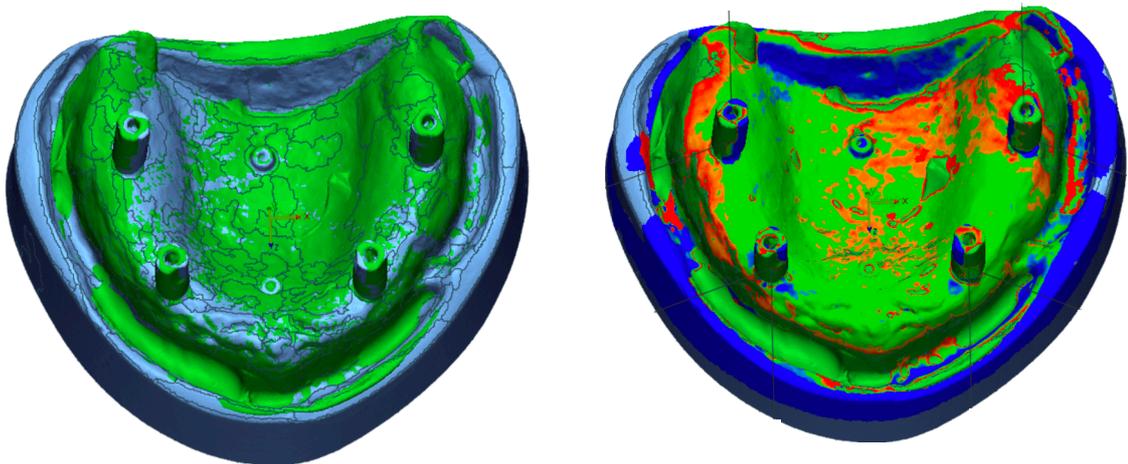
The color map shows available colors on a certain scale. Areas which are colored in green indicate an ideal fit. On the other hand, areas colored in red and blue indicate negative and positive deviations. Dark blue areas indicate greatest deviation and positive value, which refers to areas in which the impression model is wider than the reference model. Dark red areas indicate greatest deviation and negative value, which refers to areas in which the impression model is narrower than the reference model.

The user determines the values in the color scale of the software's map. In the current study, the determination of ideal deviation of impressions was made according to the American Dental Association's Specification No.19<sup>138</sup> that published acceptable properties of elastomeric impressions. In accordance with these specifications, green color value, which is considered ideal, is +/- 20 microns. On the other hand, dark blue and dark red color value, considered clinically acceptable, is +/- 150 microns.

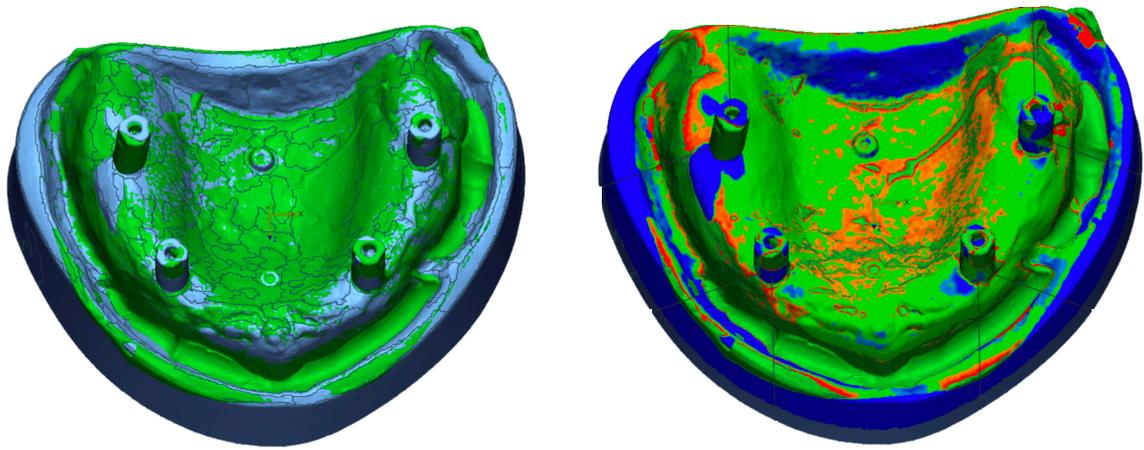
The average deviation data of the 10 scans of each impression group was calculated and inserted into an excel sheet.



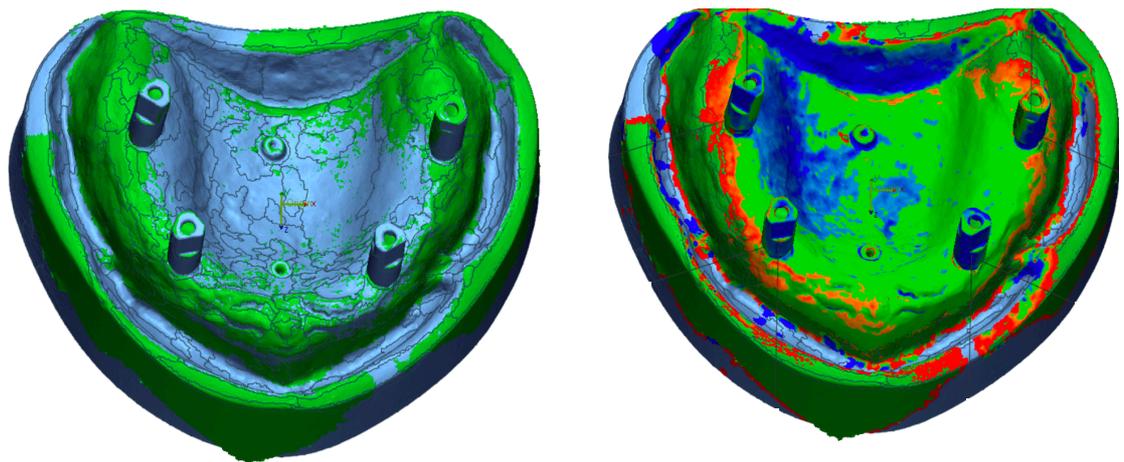
**Figure 3.18** Evaluation of an Angulated Model Impression with Polyvinylsiloxane Using Geomagic Control X



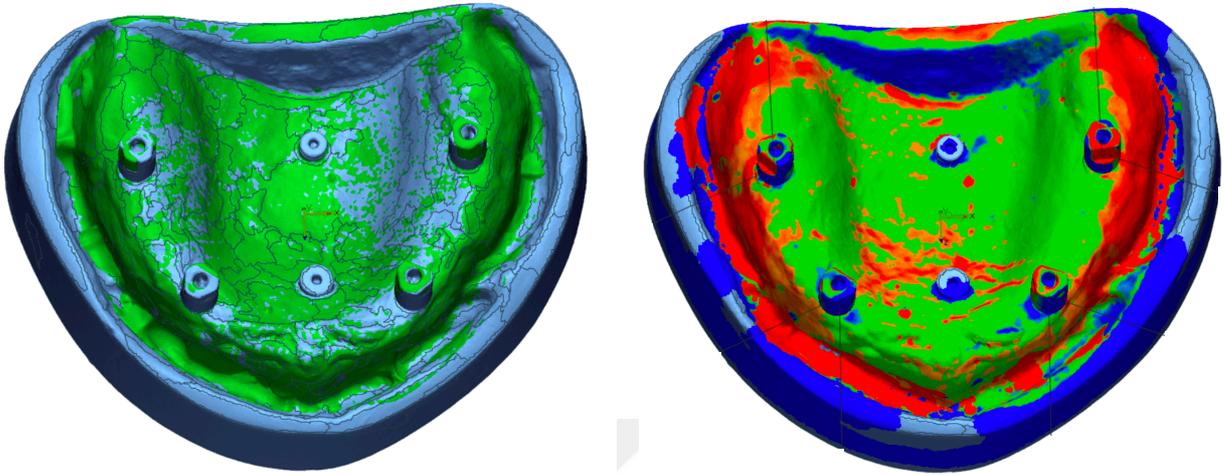
**Figure 3.19** Evaluation of an Angulated Model Impression with Polyether Using Geomagic Control X



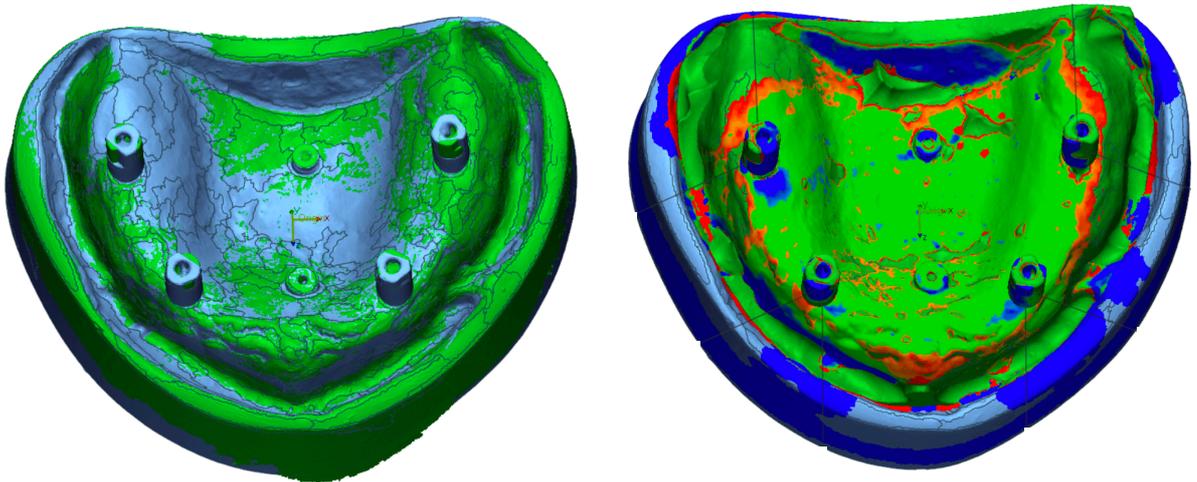
**Figure 3.20** Evaluation of an Angulated Model Impression with Polyvinyl Siloxane Ether Using Geomagic Control X



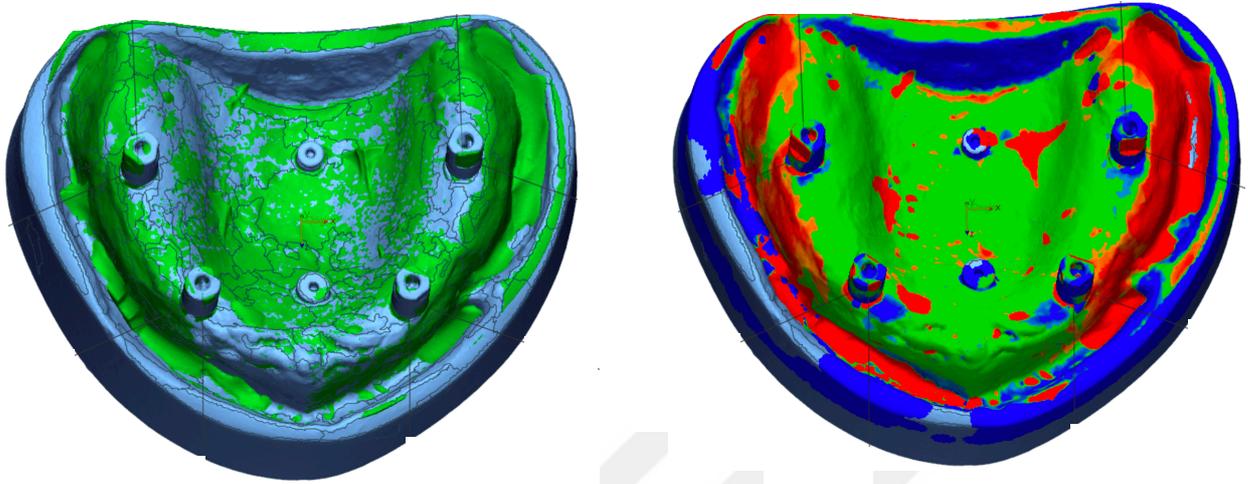
**Figure 3.21** Evaluation of an Angulated Model Impression with Digital Method Using Geomagic Control X



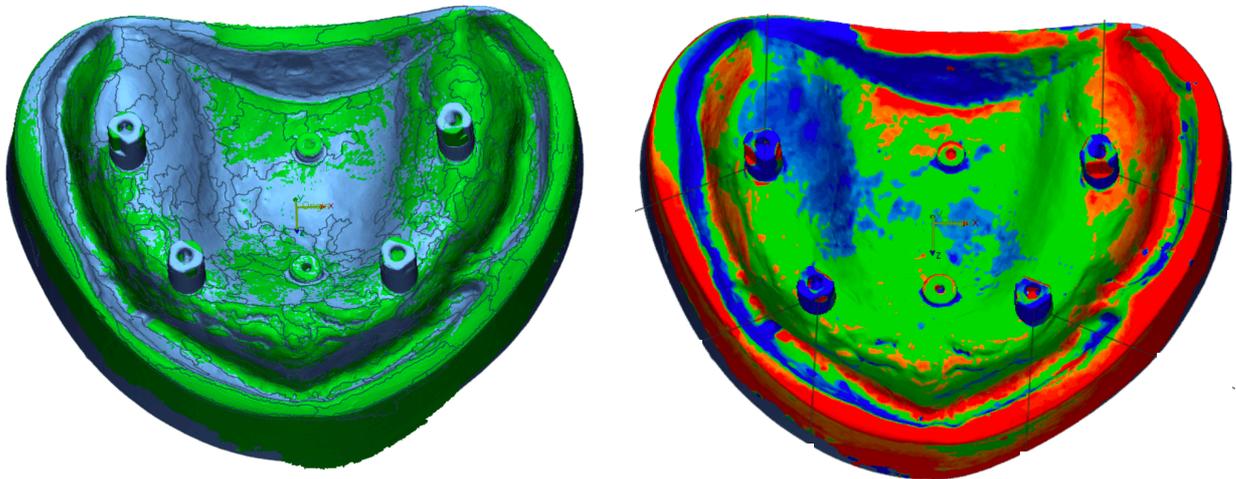
**Figure 3.22** Evaluation of a Parallel Model Impression with Polyvinylsiloxane Using Geomagic Control X



**Figure 3.23** Evaluation of a Parallel Model Impression with Polyether Using Geomagic Control X



**Figure 3.24** Evaluation of a Parallel Model Impression with Polyvinyl Siloxane Ether Using Geomagic Control X



**Figure 3.25** Evaluation of a Parallel Model Impression with Digital Method Using Geomagic Control X

### **3.8 Statistical Analysis**

The findings obtained in the study were evaluated using the IBM SPSS Statistics 22 program for statistical analysis. The normality of the parameters was assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests, and it was determined that the parameters were normally distributed. In the evaluation of the study data, two-way ANOVA test was used for assessing the deviation amount, and post hoc Tukey test was employed. Significance was evaluated at  $p < 0.05$  level.



#### 4. RESULTS

Descriptive properties of the groups are shown in Table 4.1. The distributions of the groups were considered normal since the skewness and kurtosis values of all groups were between +1.5 and -1.5. Thus parametric tests were applied for comparisons.

**Table 4.1** Descriptive Data of the Groups

Groups		N	Mean	$\bar{x} \pm Sd$	Se	Min	Max	Median	Kurtosis	Skewness
PVS	Parallel	10	0.0073	0.005	0.002	0.002	0.015	0,008	-1.302	0.264
	Angulated	10	0.0157	0.006	0.002	0,002	0.023	0.017	1.055	-1.357
PE	Parallel	10	0.0064	0.003	0.001	0.000	0.011	0.006	-0.373	-0.492
	Angulated	10	0.0120	0.004	0.001	0.005	0.017	0.012	-0.61	-0.491
PVSE	Parallel	10	0.0175	0.005	0.002	0.011	0.024	0.016	-1.031	0.065
	Angulated	10	0.0223	0.009	0.003	0.008	0.035	0.025	-1.354	-0.205
Digital	Parallel	10	0.0120	0.001	0.000	0.010	0.014	0.013	-1.298	-0.177
	Angulated	10	0.0213	0.006	0.002	0.009	0.026	0.024	1.043	-1.429

**Table 4.2** Evaluation of the Impact of Model and Impression Material Groups on Accuracy

	Type III Sum of Squares	df	Mean Square	F	p
Model Groups (Parallel/Angulated)	0.001	1	0.001	33.456	0.001 *
Impression Material Groups	0.001	3	0.001	16.053	0.001 *
Model Groups * Impression Groups	0.0001	3	0.00002	0.792	0.502
Two-way ANOVA Test	*p<0.05				

There was a statistically significant difference in terms of deviation amounts among model groups (p:0.001; p<0.05) (Table 4.2). The angulation of the implants influenced the accuracy of the impression.

There was a statistically significant difference in terms of deviation amounts among impression groups (p:0.001; p<0.05) (Table 4.2). The material used in the impression process influenced the accuracy of the impression.

The joint effect of model and impression groups on the deviation amount was not statistically significant (p:0.502; p>0.05) (Table 4.2). The angulation of the implants and the impression material did not have a joint effect on the accuracy of the impression.

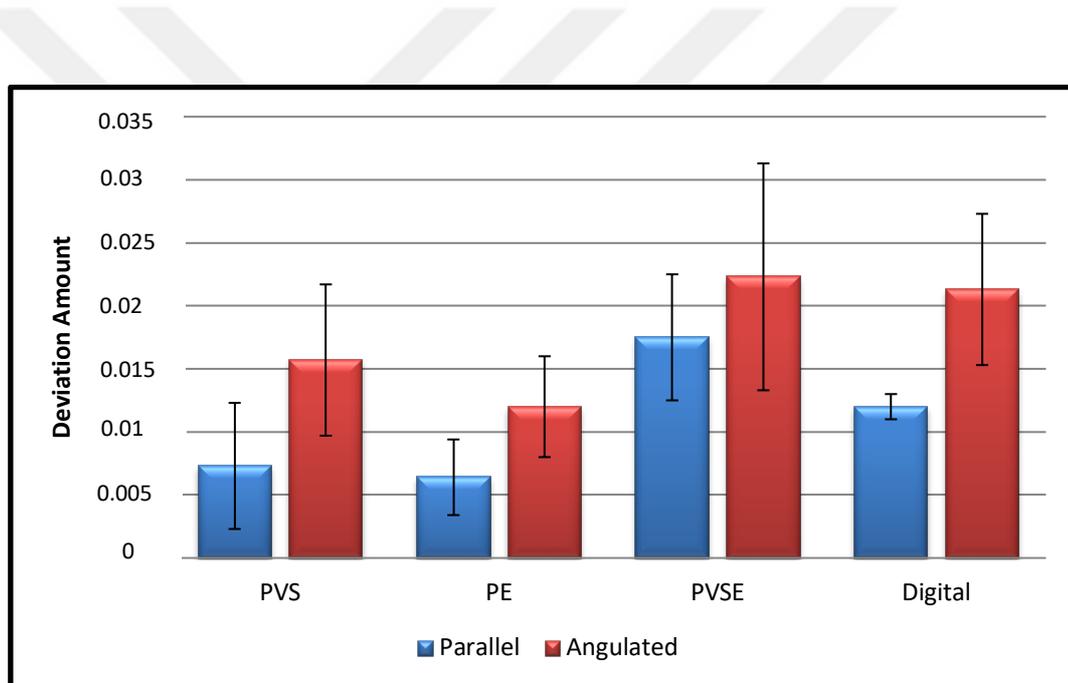
**Table 4.3** Evaluation of the Accuracy of Model and Impression groups

Impression Groups	Parallel Model	Angulated Model	p
	Mean±SD	Mean±SD	
Polyvinylsiloxane	0.0073±0.005 <sup>Aac</sup>	0.0157±0.006 <sup>Bab</sup>	0.003*
Polyether	0.0064±0.003 <sup>Aa</sup>	0.0120±0.004 <sup>Bb</sup>	0.003*
Polyvinyl siloxane ether	0.0175±0.005 <sup>Ab</sup>	0.0223±0.009 <sup>Aa</sup>	0.171
Digital	0.0120±0.001 <sup>Ac</sup>	0.0213±0.006 <sup>Ba</sup>	0.001*
p	0.001*	0.003*	

Two-way ANOVA Test \*p<0.05

The different lowercase letters in the columns indicate differences among impression groups.

The different uppercase letters in the rows indicate differences among groups



**Figure 4.1** Comparison of the Impact of Model and Impression Groups on Accuracy

In PVS group, the deviation amount of the angulated model was statistically significantly higher than the parallel model (p:0.003; p<0.05).

In PE group, the deviation amount of the angulated model was statistically significantly higher than the parallel model (p:0.003; p<0.05).

In PVSE group, there was no statistically significant difference between the deviation amounts of parallel and angulated models (p:0.171; p>0.05).

In digital impression group, the deviation amount of the angulated model was statistically significantly higher than the parallel model ( $p:0.001$ ;  $p<0.05$ ).

In the parallel model group, there was a statistically significant difference among impression groups in terms of deviation amounts ( $p:0.001$ ;  $p<0.05$ ). Based on the post hoc analysis, the deviation amount of PVSE group was statistically significantly higher than PVS Group ( $p:0.001$ ), PE Group ( $p:0.001$ ), and digital impression group ( $p:0.019$ ) ( $p<0.05$ ). The deviation amount of digital impression group was statistically significantly higher than PE Group ( $p:0.016$ ) ( $p<0.05$ ). There was no statistically significant differences among the other groups ( $p>0.05$ ).

In the angulated model group, there was a statistically significant difference among impression groups in terms of deviation amounts ( $p:0.003$ ;  $p<0.05$ ). Based on the post hoc analysis, the deviation amount of PE Group was statistically significantly lower than PVSE Group ( $p: 0.007$ ) and digital impression group ( $p:0.016$ ) ( $p<0.05$ ). There was no statistically significant differences among the other groups ( $p>0.05$ ).

## 5. DISCUSSION

To rehabilitate function and aesthetics of patients with complete edentulism, implant-supported restorations are a widely accepted treatment option<sup>139</sup>. The accurate transfer of the position and angulation of the implants inside the mouth to the working model is essential for a successful implant-supported restoration.<sup>140</sup> The passive fit of the restoration cannot be achieved if the implant position and angle are not accurately transferred to the model. Passive fit ensures that the infrastructure of the prosthesis does not cause excessive force or tension around the abutment, implant, and the bone surrounding it. If passive fit is not achieved, biomechanical complications might occur such as; bone loss, porcelain fracture, screw loosening or fracture.<sup>130</sup>

To achieve passive fit, accurate working casts must be produced. Thus, accuracy of implant impression have a significant role in this matter. The type of impression technique used, splinting of the impression copings, type of implant connection, impression material type, number of implants and their angulations, dimensional stability of the gypsum that is used in the fabrication of the working cast are examples of factors that have an effect on the accuracy of impression of implant-supported restorations.<sup>15,26,141–144</sup> Implant-supported restorations' clinical fit at the implant-abutment junction is directly dependent on the impression accuracy and the production of an accurate definitive cast that exactly transfers it's correct intraoral position so that the prosthesis can have long-term stability.<sup>35,141</sup>

As the digital technology advances, digital systems are integrated to the dental diagnosis and treatment phases especially with the use of intraoral digital scanners. The development of CAD/CAM technology has become an alternative for conventional impression methods used in the production of implant-supported restorations. Elimination of tray selection, less risk of distortion during impression procedure, no pouring, no disinfection, no shipping to the dental laboratory, and increased patient comfort are examples of the advantages that are provided with the introduction of intraoral scanners into daily dental practice.<sup>90</sup>

The aim of this study is to evaluate and compare the accuracy of digital and conventional impression techniques with different materials in multiple implants with

different angulations. Design of the current study includes 8 groups: impression of parallel model with polyvinylsiloxane, polyether, polyvinyl siloxane ether, digital method, and impression of angulated model with polyvinylsiloxane, polyether, polyvinyl siloxane ether, digital method.

The material from which the reference models are fabricated is of vital importance for the accuracy results of the impressions. Various materials have been used in studies to manufacture a reference model. Stainless steel<sup>101,145</sup>, dental stone<sup>146,147</sup>, polyurethane<sup>69,148</sup>, epoxy resin<sup>137</sup>, and pink acrylic resin<sup>90</sup> are examples of materials that were used in previous studies to fabricate reference models. Metal-based reference models have superior physical and mechanical quality. However, metal models were not preferred in the current study due to the complexity of implant placement on the model, and reflection of the light from the surface features.<sup>69</sup> Another alternative was dental stone models, but dental stone models are fragile and susceptible to water absorption which makes their use as a reference model quite impractical. On the contrary, dental stone models have matt surface properties thus intraoral scanners can record their structures easily.<sup>69,108</sup> Epoxy resin and polyurethane materials are very precise materials that does not stick to silicone impression materials which makes them preferable when compared with stone models. Polyurethane material is also affordable, strong and has the ease of implant insertion.<sup>149</sup> As a result, an upper jaw polyurethane model was used to ease the impression process and reflect anatomical conditions.

To implement the clinical impression phase of all-on-4 restorations, abutment level impression with multi-unit abutments were taken in this study. Moreover, a study that compared different impression techniques when using all-on-4 implant treatment protocol conducted by Siadat *et al.*<sup>150</sup>, also supported this decision. They reached the conclusion that less displacement was observed with the open-tray method, and abutment-level impressions were found to be more accurate.

Splinting technique was used in all of the groups of this study with cut bars which were attached between the impression copings by using cold acrylic resin. Several authors advised that splinting the impression copings together increased the accuracy and avoided the rotational distortion that occurs while implant analogs are fastened to their related copings.<sup>38,44</sup> A systematic review conducted by Papaspyridakos *et al.*<sup>35</sup> also revealed that

impression accuracy significantly increases when the copings are splinted in both cases of partial and complete edentulism implant cases. Several materials can be used to splint the copings together. Light-cured composite resin, impression plaster, orthodontic wire, and acrylic resin are examples of such materials.<sup>18,151</sup> Acrylic resin is the most used splinting material. Its main disadvantage is the dimensional shrinkage of resin. Mojon *et al.*'s<sup>152</sup> study revealed that the acrylic resin has a total shrinkage of 6.5-7.9% and approximately 80% of the total shrinkage occurs in the first 17 minutes. Some authors affirmed that the shrinkage of acrylic resin can result in the distortion of the impression coping position which is embedded within the impression material.<sup>153</sup> To avoid this disadvantage, current study utilized the use of prefabricated transparent bars to connect the copings with the use of self-cure acrylic resin. Thus, a fast and easy method, applicable to clinical use which avoids distortion, was used.<sup>23</sup>

For conventional impression taking of full mouth implant restorations, the most recommended materials are polyvinylsiloxane and polyether according to the literature.<sup>154</sup> There are several studies that suggest that the best outcomes can be achieved with polyether.<sup>61,155,156</sup> On the other hand, there are also studies stating that polyvinylsiloxane and polyether have no statistically significant difference in terms of impression accuracy.<sup>20,157-160</sup> The effect of implant angulation is another factor that affects the accuracy outcomes of impressions, and there are several studies that investigate this effect<sup>15,41,44,135,142,143</sup>. As a result, the current study was conducted by using two main models that displayed parallel and angulated cases. Polyvinyl siloxane ether is a relatively new elastomeric impression material that can also be used in the impression of implant-supported restorations.<sup>6,161-165</sup> There are limited number of studies in the literature with PVSE to reach a conclusion about its accuracy of impression outcomes, which is why it was included in the current study to investigate its outcomes in both parallel and angulated implant cases.<sup>6,161-164,166</sup> Moreover, the current study also compared the accuracy results of PVSE and the digital method, which was not examined before.

The methodology of impression taking processes were standardized to avoid the effect of other variables in the study. Stock open trays with window space corresponding to the implant site were used in each impression. 3mm space was present between the reference models and the trays so that an enough, uniform thickness of impression

materials was present. Since impression material thickness affects the outcome of impressions, the material thickness was eliminated as a variable in the current study.<sup>167</sup> An auto-mixing machine and garant dispenser was used for the impression materials so that the inhomogeneity of hand-mixing is avoided. To evade the effect of impression material dimensional changes, manufacturer instructions were followed during the impression taking and pouring of the cast stages. Double mixing method was used during pouring of the cast to lessen the effect of the dimensional change of the stone.<sup>45</sup> Moreover, type-IV dental stone was used in the making of the cast since it is the best stone material in terms of going through less dimensional changes.<sup>168</sup> A single operator performed all of the laboratory steps to avoid intraoperator errors.

Digital impression accuracy is affected by many factors including intraoral scanner technology, software of the device, the experience, performance, and knowledge of the operator, the scanning pattern and protocol, scan body characteristics, and clinical factors.<sup>14,169</sup> According to a study conducted by Gimenez *et al.*<sup>90</sup>, operators who are inexperienced take longer time to scan, and accuracy is not always affected by experience. In another study by Gimenez *et al.*<sup>107</sup>, it was found that the experience of the operator increases the impression's accuracy, but the learning curve can be reached with 15 scans.<sup>107</sup> In the current study, all of the scanning was performed by a single operator. Before the scans were performed, the operator was provided with appropriate information by the manufacturer's representative and 15 test scans were performed on the scanner. By this way, the variable of operator experience was attempted to be eliminated. All scans were performed with the same intraoral scanning device, and the scanning protocol of the manufacturer was followed.

Lightning conditions and temperature are other factors that affect the accuracy of digital impressions. In a study by Revilla-Leon *et al.*<sup>170</sup>, dental unit light (10,000 lux), room light (1003 lux), daylight (500 lux), and darkness (0 lux) were compared. It was found that room light environment provided significantly better outcomes in full arc scans.<sup>170</sup> Revilla-Leon *et al.*<sup>116</sup>. conducted another study that evaluated three different intraoral scanners for their accuracy under four different lightning conditions. It was found that Trios 3 device gave the best outcomes under room lightning. In accordance with the discussed studies, the current study scans were conducted with Trios 3 device under room lightning to avoid the effect of lightning conditions on the analysis. In a study

conducted by Kambhampati *et al.*<sup>171</sup>, the effect of temperature changes on the dimensional stability of elastomeric impressions was assessed. They concluded that impressions were most accurate at 25°C temperature. Therefore, the current study scans were conducted at room temperature of 25°C.

There are different techniques used to assess impression accuracy in the literature. Virtually measuring linear, angular, or 3D surface deviations, marginal fit checks between implant abutments and restoration substructure, measuring the stress on the substructure are examples of such techniques.<sup>154</sup> The current study used the virtual 3D deviation measurement method due to the digital nature of the test models acquired. All conventional impression test models were scanned with an extraoral scanner for virtual assessments since the discrepancies of extraoral scanners are very small and vary between 6 and 10µm.<sup>123</sup>

Many studies in the literature used Geomagic Control X (Geomagic, USA) software to calculate the deviation values of control and test groups.<sup>88,147,172</sup> In accordance with the mentioned studies, the current study used the software to overlap data in the “best-fit alignment” mode. The reference data and the test data in STL forms were superimposed onto each other in the virtual environment of the software, and the surface deviations were calculated. The registration of the “best-fit alignment” was performed over the reference points, which were on the midline of the palate of the models. The deviations were measured according to these reference points and not the implants because discrepancies that might occur on the implant positions might lead to misleading results according to several studies.<sup>150,165,173,174</sup> In the current study, the determination of ideal deviation of impressions was made according to the American Dental Association’s Specification No.19<sup>138</sup> that published acceptable properties of elastomeric impressions. In accordance with these specifications, green color value of the software, which is considered ideal, is +/- 20 microns. On the other hand, dark blue and dark red color value of the software, considered clinically acceptable, is +/- 150 microns. All of the test groups of the present study yielded results which were clinically acceptable.

The first hypothesis of the current study, there is no statistically significant difference between conventional impressions taken with polyvinylsiloxane, polyether, polyvinyl siloxane ether and digital impressions, is rejected according to the findings of

this study. There was a statistically significant difference in terms of deviation amounts among impression groups ( $p:0.001$ ;  $p<0.05$ ). The material used in the impression process influenced the accuracy of the impression. The second hypothesis, there was no statistically significant difference between impressions of parallel and angulated implants, is also rejected according to the findings of the study. There was a statistically significant difference in terms of deviation amounts among model groups ( $p:0.001$ ;  $p<0.05$ ). The angulation of the implants influenced the accuracy of the impression.

In the PVS ( $p:0.003$ ;  $p<0,05$ ), PE ( $p:0.003$ ;  $p<0.05$ ), and digital impression ( $p:0.001$ ;  $p<0.05$ ) groups of the present study, the deviation amount of the angulated model was statistically higher than the parallel model. In the PVSE group, the deviation amount increased in the angulated group, but there was no statistically significant difference between the parallel and angulated models ( $p:0.171$ ;  $p>0.05$ ). The reason why the conventional impression groups are affected by the angulation of the implants could be impression material deformation during removal because of undercuts leading to distortion of the casts, or misfit of the impression coping and analog.<sup>175</sup> The reason why digital group was affected by implant angulation could be increased distance between scan bodies in the full mouth impressions, which leads to incorrect stitching of images acquired by the scanner.<sup>113,176</sup> To fully comprehend the effect of implant angulation on the digital impression group, clinical studies should be conducted since material deformation is not a factor in digital impressions.

In the parallel model group, the deviation amount of PVSE group was statistically significantly higher than PVS group ( $p:0.001$ ), PE group ( $p:0.001$ ), and digital impression group ( $p:0.019$ ) ( $p<0.05$ ). The deviation amount the digital impression group was statistically significantly higher than PE group ( $p:0.016$ ;  $p<0.05$ ). In the angulated model group, the deviation amount of PE group was statistically significantly lower than PVSE group ( $p:0.007$ ) and digital impression group ( $p:0.016$ ;  $p<0.05$ ). PE group provided the most accurate results with the least amount of deviation in all groups. During the polymerization reaction of PE, the imine groups on the polymer chain result in the increase of the degree of cross-linking and provides higher rigidity<sup>177</sup>. Therefore, PE having much-reduced rotational discrepancy could be reason behind the findings of the current study. PVSE yielding the highest amount of deviation in all groups could be because of having the lowest elastic recovery value since elastic recovery maintains the

dimensional stability of the impression and avoids discrepancies once the tray is removed.<sup>163</sup> The digital groups not providing accurate outcomes could be because of the methodology of the current study since full mouth impressions were taken. Intraoral scanning system accuracy decreases when the scanned area and distance between scan bodies increase. The errors that are seen between the start and end points of the scanning process results in the highest error at endpoints.<sup>178</sup>

There are several studies in the literature that compare the accuracy of impression materials for implant restorations. Aidasani *et al.*<sup>166</sup> conducted an in vitro analysis in which they examined the accuracy of polyvinylsiloxane, polyether, and polyvinyl siloxane ether. Their conclusion was that polyether material was more precise than polyvinylsiloxane and polyvinyl siloxane ether. Their results were similar to the current study's findings in which polyether was found to be more accurate in both parallel and angulated models.

Guo *et al.*<sup>177</sup> conducted a systematic review and meta-analysis on optimal impression materials for implant-supported fixed complete dentures. The impression materials that they based their research on was polyether and polyvinylsiloxane. They concluded that PVS and PE had similar accuracy in most cases. However, when implants are placed in angles greater than 15°, PE provided better results. In the present study, PE yielded better results in both parallel and angulated cases when compared with PVS. Current study's angulated model's results are supported with this systematic review's findings.

In a research by Palantza *et al.*<sup>179</sup>, the accuracy of full mouth implant impressions with polyether, polyvinylsiloxane, and two digital impressions with two different intraoral scanners was assessed. They fabricated a master mandible model which had two implants in the canine regions and two 15° angulated implants in the molar region. Conventional impressions were taken with open trays without splinting. Digital impressions were taken with Trios 3 and HERON devices. Trios 3's working principle is a combination of parallel confocal microscopy and structured light. HERON's working principle is active stereo imaging made with continuous scans and stitching of color and depth data. For assessing accuracy, they used Viewbox 4 software. Their results were that PVS and PE were statistically significantly superior to the digital impressions of both

devices. There was no statistically significant difference between PE and PVS. They also found that Trios 3 yielded statistically significantly better results than HERON. The current study's angulated groups were compared with Palantza *et al.*'s<sup>179</sup> study since the models were similar except the molar implants of the current study's model had 30° angulations, and both studies' results supported each other. In the present study, PE impression of the angulated model was statistically significantly superior to digital group and had no statistically significant difference with PVS even though it showed less 3D deviation.

Kurtulmuş-Yılmaz *et al.*<sup>164</sup> conducted a study in which they examined polyvinylsiloxane, polyether, and polyvinyl siloxane ether in models that simulate parallel and angulated implants. They reported that implant angulations increase the deviations of all of the materials. In their parallel model, they reported that PVSE had statistically significantly higher deviation, whereas PE and PVS did not have statistically significant difference between them. In their angulated models, they reported that PVSE had statistically significantly higher deviation, and PVS had significantly low deviations. The fact that they found PVSE to have the highest deviation in both parallel and angulated models support the findings of the current study. On the other hand, the current study's findings were that in angulated cases PE yielded better results than PVS, but the difference was not statistically significant. This difference in findings could be because of having different reference models since Kurtulmuş-Yılmaz *et al.*'s<sup>164</sup> models represented partial edentulism whereas the current study's models represented complete edentulism. Partially dentate arches cause anatomical undercuts, thus greater modulus of elasticity of PVS could be an advantage in such cases.

In a study by Siadat *et al.*<sup>163</sup>, the accuracy of impressions of polyvinylsiloxane and polyvinyl siloxane ether was examined in angulated implants. They reported that PVS yielded more accurate results when compared with PVSE in angulated cases. Their findings support the findings of the current study.

In the research conducted by Vojdani *et al.*<sup>162</sup>, the accuracy of polyvinylsiloxane, polyether, and polyvinyl siloxane ether was examined in parallel and nonparallel implants. They found that in parallel implant cases, impression accuracy was not affected by the type of material in a statistically significant way. In angulated cases, they found

that PVS yielded significantly more accurate impressions than PE and PVSE. The findings of Vojdani *et al.*<sup>162</sup> differ from the present study. The current study concluded that in the parallel model, PE had significantly less deviation than PVSE, PVS had significantly less deviation than PVSE and even though there was no statistically significant difference, PE had less deviation than PVS also. Moreover, in the angulated model of the current study, PE had significantly lower deviation than PVSE. PE had lower deviation values than PVS and PVS had lower deviation values than PVSE, but there was no statistically significant difference between them. The difference in findings of the discussed studies could be since Vojdani *et al.*'s<sup>162</sup> study models were of a partially dentate maxilla. Partially dentate arches cause anatomical undercuts, thus greater modulus of elasticity of PVS could be an advantage in such cases.

Moura *et al.*<sup>180</sup> evaluated polyvinylsiloxane and digital impression method's accuracy in implants with and without any angulation. They found that there was no statistically significant difference between PVS and digital impression method. Moreover, implant angulation did not significantly affect the accuracy of the impression. The findings are different from the results of the present study. One of the reasons could be that the angulation of Moura *et al.*'s<sup>180</sup> model is 15° and has external hex connection, whereas the current study has 30° angulated implants with internal hex connection.

In a study by Alikhasi *et al.*<sup>175</sup>, accuracy of different impression techniques with angled implants of different connection types were assessed. Two main models had two anterior straight and two posterior angled implants. The difference between models were connection types (internal and external hex). Digital method (Trios 3Shape) whose working principle is a combination of parallel confocal microscopy and structured light, and conventional methods (direct and indirect) with polyvinylsiloxane was used as impression techniques. They found that digital impressions yielded better results than conventional impressions with PVS. Moreover, they found that digital impressions were not affected by the angulation of implants. Their results are different from the findings of the current study. This difference could be due to not taking the impression with multi-unit abutments, not splinting the impression copings, and using different implant manufacturers, thus having different machine tolerance of prosthetic components, and different scan bodies (PEEK vs. titanium).

Baig *et al.*<sup>161</sup> conducted a study in which they examined multi-unit implant casts acquired from polyether and polyvinyl siloxane ether and assess the effect of splinting. Their results were that there was no statistically significant difference between PE and PVSE regardless of splinting. The difference between Baig *et al.*<sup>161</sup> and current study could be due to several factors such as; the current study having lesser number of implants and different angulations, reference model and gypsum models were not scanned with extraoral scanner but with a coordinate measuring machine in Baig *et al.*'s<sup>161</sup> study, operator induced changes, and different implant manufacturer and components.

In the research conducted by Enkling *et al.*<sup>6</sup>, performance of implant impressions with polyether and polyvinyl siloxane ether was examined. They found that PE and PVSE yielded results that had no statistically significant difference between them. Their findings do not correlate with the findings of the present study. The difference in findings could be because of different assessment methods. Enkling *et al.*<sup>6</sup>'s study consisted of 10 subjects with three to five implants each and assessing the accuracy with the clinical fit of control key manufactured on abutments of the master model. On the other hand, the current study used two specific reference models with four implants and different angulations and assessed the impression models by superimposing them on a virtual software.

Drancourt *et al.*<sup>181</sup> evaluated the accuracy of conventional and digital impressions acquired from four intraoral scanners. For the digital impressions, they performed two different scanning methods. Trios 4, Primescan and i500 scanners were used in the first scanning method. They first scanned the reference model starting from the occlusal surface from the right molar region towards the left molar region, then moved to the buccal regions and lastly to the palatal surfaces without any scan bodies. Then a second scan was made with scan bodies in position, after the circular cut and implant areas removal. CS 3600 scanner was used in the second scanning method. The first step of the scanning process was identical to the first method. After the circular cut of the implant areas, one of the scan bodies was placed, scanned, and then removed. Same steps were followed for all implants and their scan bodies. Their research revealed that conventional impression yielded more accurate results when compared with digital impression. Their results support the findings of the current study.

In an in vitro study by Gómez-Polo *et al.*<sup>176</sup>, the effect of impression technique and implant angulation on accuracy was examined. Conventional impressions were taken with polyether using splinted open-tray method. For the digital impression groups Trios 3 device was used. The digital impression groups were intraoral scan, intraoral scan with a splinting framework, and intraoral scan combined with Cone Beam Computerized Tomography (CBCT) scan. According to their results, parallel implants yielded better outcomes than unparallel implants, and conventional methods were found to be more accurate. They also found that splinting and combining the intraoral scans with CBCT yield better results. Their findings about the angulation correlate with the findings of the present study.

Kosago *et al.*<sup>182</sup> conducted a study in which they researched the accuracy between conventional and different intraoral scanner impressions of a mandibular edentulous arch with five implants. They used four different scanners which were Trios 4, iTero Element 2, Primescan, and a PIC camera which utilizes stereophotogrammetry technique. Their research revealed that polyether impression had significantly highest deviation when compared to the other digital methods, stereophotogrammetry provided the highest accuracy, and Trios 4 and Primescan delivered more accuracy than iTero Element 2. Their findings differ from the findings of the current study which found that PE had significantly better outcomes in both parallel angulated cases. There could be several reasons why there is difference in findings of the studies. Firstly, Kosago *et al.*<sup>182</sup> used five implants with two of them having 17° angulations whereas the present study had four implants with 30° angulations of posterior implants. Secondly, Kosago *et al.*<sup>182</sup> used a mandibular model whereas the current study used a maxillary model. Lastly, Kosago *et al.*<sup>182</sup> used different brands and versions of intraoral scanners.

In the research conducted by El Osta *et al.*<sup>183</sup>, the accuracy of conventional impression with polyether and digital scans by five different intraoral scanners (Trios 3, Trios 4, Primescan, CS 3600, i-500) were evaluated in a maxillary free-ended partial edentulism model. In the scanning process with Trios 3, Trios 4, and Primescan the impressions were taken in a single step. On the other hand, in the scanning process of CS 3600 and i-500, an initial scan was made without the scan bodies followed by a second scan that record the areas with scan bodies in position. According to their findings, Trios 3 device yielded highest accuracy followed by i-500, Trios 4, CS 3600, Primescan and

conventional impressions with polyether respectively. Their results negate the findings of the current study. The difference in findings could be since El Osta *et al.*<sup>183</sup> used a partial edentulism model while the present study used a model with complete edentulism. Partially dentate arches cause anatomical undercuts, thus low modulus of elasticity of PE, could be disadvantage in such cases.

Menini *et al.*<sup>9</sup> evaluated the accuracy of conventional and digital impression techniques on multiple implants. Digital impressions were taken with True Definition Scanner by 3M ESPE using the 3D in motion technique. Their findings revealed that digital impressions provided better results than conventional impressions with polyether. Their results did not correlate with the results of the current study. There could be several reasons for different findings of the studies. Firstly, Menini *et al.*<sup>9</sup> used a rectangular model as their master cast whereas the current study used a reference model of maxilla with anatomical landmarks. Secondly, Menini *et al.*'s<sup>9</sup> study used a different intraoral scanner with different working principles, assessed accuracy with framework fabrication and coordinate measuring machine while the present study obtained the STL files of the impression models with an extraoral scanning device and superimposed them on a virtual software.

In the research made by Elshenawy *et al.*<sup>184</sup>, accuracy of casts acquired from three conventional impression techniques (polyvinylsiloxane) with implants of different angulations was assessed. According to their results impression accuracy was negatively affected by implant angulation. Their findings correlate with the findings of the current study.

In a study by Gómez-Polo *et al.*<sup>113</sup>, the accuracy of digital implant impressions was examined in different scan body heights and implant angulations. They utilized the Trios 3 device in their scans. They found that implant angulation significantly causes discrepancies in the impressions. Their results correlate with the results of the present study in which digital impression group had significantly higher deviation in the angulated model when compared with the parallel model.

In a study conducted by Irani *et al.*<sup>185</sup>, effect of impression material and implant angulation on accuracy was examined. They used polyether and polyvinylsiloxane

materials. They placed the implants with 10°, 20°, 30° angulations. According to their results, there was no statistically significant difference between PE and PVS. Moreover, implant angulations also did not significantly affect accuracy. Their findings negate findings of the present study. This negation could be because Irani et al<sup>185</sup> used external hex connection implants and because their models had only two implants on blocks representing partially dentate patient. On the other hand, the current study had implants with internal connection and reference models with four implants on a maxillary jaw model with anatomical landmarks.

Mpikos *et al.*<sup>41</sup> evaluated the effect of impression technique and implant angulation on impression accuracy. They used polyether as the impression material. Their results showed that implant angulation had a significant negative effect on accuracy when implants with internal connections were utilized. Their findings support the findings of the current study.

Geramipناه *et al.*<sup>178</sup> conducted an in vitro study in which they examined the effect of arch size and angulation of implants on the accuracy of digital impressions with Trios 3 and CEREC Omnicam devices. They found that CEREC Omnicam device yields better results than Trios 3, arch length increases the errors in the scans, and they concluded that angulation of implants had no significant effect on the accuracy of impressions. Their results of implant angulations do not correlate with the findings of the present study. This difference in findings could be due to not taking the impression with multi-unit abutments, using different implant manufacturer's, thus having different machine tolerance of prosthetic components, and different scan bodies (PEEK vs. titanium), and using a different scanning device to scan the reference models (CMM vs. extraoral scanner).

There are several limitations of the current study. First of all, this study was an in vitro study. Even though clinical scenarios were tried to be simulated closely, hardness, structure and wettability of the master models are different from oral tissues. Moreover, thermal contraction of the impression material from mouth to room temperature was not modeled since all impressions were taken in laboratory conditions. Impression taking complications were not encountered too since jaw movements, saliva, or interference of the scanning tip with buccal tissue and tongue, which can alter the results. Further in vivo

studies are essential to yield more clinically applicable findings. Secondly, a single intraoral scanner, single scanning body design, and measurement method, and a single brand of each impression material was used to assess the accuracy of impressions. The use of different manufacturers, materials, designs and methods could yield different results. Thirdly, the present study was conducted with the use of only four implants, angulation was limited to 30°, and only internal connection implants were utilized. The use of higher number of implants, different angulations and implants with external connection can yield different results. Fourthly, this study's research methodology did not include the alignment between the scan body of the CAD library and scan body of the digital scan. It also did not include the manufacturing of the complete-arch implant supported prosthesis. Manufacturing of the framework and prosthesis can allow the use of further assessments such as the one-screw test and yield more elaborate results. Lastly, for the acquisition of the virtual models of the reference models, an extraoral scanner was used in the current study. If a CMM machine or another scanning device with smaller discrepancy values is used obtain 3D models in STL format, different results can be obtained.

## 6. CONCLUSION

According to the results of the present study;

1. The material used in the impression process influences the accuracy of the impression (p:0.001; p<0.05).
2. Implant angulation has a negative effect on accuracy (p:0.001; p<0.05).
3. Polyether yields the best results of accuracy in the impression of both parallel (p:0.001; p<0.05) and angulated (p:0.007; p<0.05) full mouth cases.
4. Even though polyvinyl siloxane ether is a relatively new material promising to unite the best properties of polyether and polyvinylsiloxane, it does not yield accurate impression results in both parallel (0.001; p<0.05) and angulated (p:0.007; p<0.05) full mouth cases.
5. Digital impressions yield less accurate results in both parallel (p:0.016; p<0.05) and angulated (p:0.016; p<0.05) full mouth cases when compared with impressions taken with PE.
6. All of test groups provided accuracy results which were clinically acceptable according to the American Dental Association's Specification No.19.

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## 8. APPENDIX

### 8.1 CURRICULUM VITAE

#### Personal Information

<b>Name</b>	Akanay	<b>Surname</b>	Çopuroğlu
<b>Place of Birth</b>		<b>Birthdate</b>	

#### Educational Status

Degree	Field	Name of Institution of Graduation	Year of Graduation
Doctoral	Prosthodontics	Yeditepe University	2024
Graduate	Faculty of Dentistry	Yeditepe University	2020
High School	Science	Üsküdar American Academy	2015

Foreign Languages	Foreign Language Proficiency Exam Scores
English	

#### Publications and Presentations

Çopuroğlu A, Öztürk BB, Ağca U, et al. Occlusion in implant prosthodontics. <i>Yeditepe J Dent.</i> 2022;18(3):68-74. Doi: 10.5505/yeditepe.202203360
Çopuroğlu A, Özkurt Kayahan Z. Monolitik Zirkonya Adeziv Köprü Restorasyonu: Olgu Sunumu. <i>TDB 27. Uluslararası Diş Hekimliği Kongresi</i>
Çopuroğlu A, Özkurt Kayahan Z, Kazazoğlu E. Accuracy of digital and conventional impression techniques in multiple implants with different angulations: Accepted Oral Presentation: <i>FDI World Dental Congress – Istanbul 2024</i>

#### Conference Attendance

2. Ulusal Genç Diş Hekimliği Derneği Öğrenci Kongresi, 5-7 Kasım 2021 Antalya, Türkiye
Nobel Biocare Türkiye Sempozyumu, 11-14 Kasım 2021, Antalya, Türkiye
9. Uluslararası Endodonti Sempozyumu, 19-22 Mayıs 2022, Mardin, Türkiye
Türk Diş Hekimleri Birliği 26. Uluslararası Diş Hekimliği Kongresi, Bilimsel Komite Üyesi, 8-11 Eylül 2022, İstanbul, Türkiye
18. GREATIST Uluslararası Diş Hekimliği Kongresi 21-23 Ekim 2022, İstanbul, Türkiye
İstanbul Diş Hekimleri Odası 1. İstanbul Buluşması, 7-8 Nisan 2023, İstanbul, Türkiye
13. Ulusal TDB Öğrenci Kongresi, Moderatörlük, 1-2 Eylül 2023, İstanbul, Türkiye
İstanbul Diş Hekimleri Odası 2. İstanbul Buluşması, 22-23 Mart 2024, İstanbul, Türkiye